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Monitoring of recent crustal movements around Cairo by repeated gravity and geodetic observations

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Abstract: The mass distribution and density inhomogeneities are one of the main factors affecting Earth's dynamics. The temporal gravity variations were used to understand the surface tectonics and geodynamic modeling after the occurrence of an earthquake of 1992. The gravity field changes have been used for monitoring recent crustal movements in the area around Cairo and Southern part of Delta, Egypt. More than five successive gravity measurement campaigns were performed in parallel with the geodetic technique (GPS).

The gravity changes were determined and correlated with seismic activity for all periods of observations. It was found that there is a certain relation shown by increasing of gravity values before the main seismic activity. As an example, a relatively considerable increase of gravity values was noticed for the network between the epochs of 2000 and 2004. Otherwise, the temporal gravity variations exhibited a considerable decrease in gravity values between the two campaigns of 2004 and 2007 for the same stations. This behavior could be explained by compressive deformation and strain buildup stage before the Southwestern Cairo earthquake (July 31, 2005 with magnitude of 4.3) and the stress release stage occurred after the main-shock. In addition, the results of geodetic measurements of the network around Cairo after five campaigns showed that the estimated horizontal velocities for almost of points are 5.5 mm/year in approximately NW direction.

Key words: temporal gravity variations, earthquakes, geodynamics

1. Geological and seismological background

As for the geological background, Egypt is located in the northeastern part of Africa and extends beyond the Gulf of Suez and the Suez Canal into Asia. The tectonic evolution of Egypt is characterized by a number of stages since Precambrian. According to *Said (1962)*, *Youssef (1986)* and *Smith (1984)*, Egypt is classified into three major geological provinces.

The greater part of northern Egypt belongs to the unstable shelf area and most of the area was covered by the principal marine transgressions at least since Paleozoic time.

The main types of macrostructures in the study area are monoclines and faults (Fig. 1). Most of these faults have a Post Eocene age of deformation. The major faults that affect the study area have the N–W, E–W and N–E directions (Fig. 1) *(Youssef, 1986)*. The N–W trending faults are the most predominant ones. Analysis of these faults indicates that the main stress regime is the tensile stress *(Abdel Tawab, 1986)*. These tensile stresses are created from right lateral divergent strike slip movement on a deep seated of faults. All solutions in Cairo region showed normal faulting mechanism with a strike-slip component.

Egypt is considered as a territory of moderate earthquake activity. Information on historical earthquakes is documented in the annals of ancient

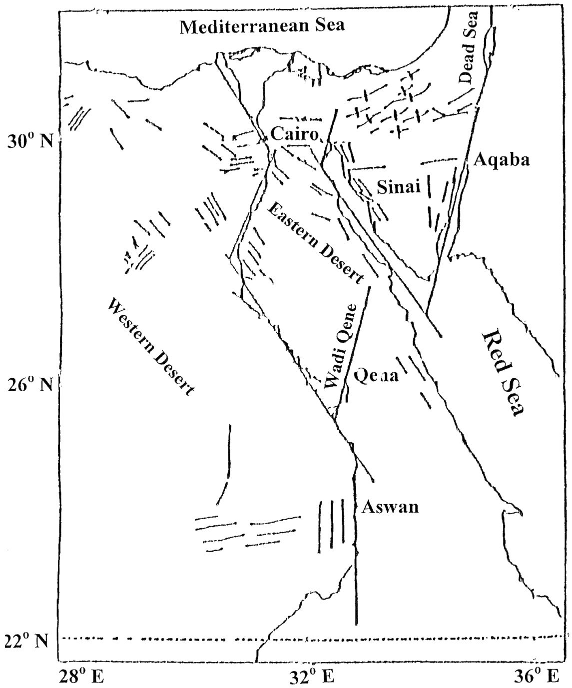

Fig. 1. The main structural pattern of Egypt *(Youssef, 1986)*.

Egyptian history and Arabic literature. According to *Ambraseys (1991)* and *Maamoun (1979)*, about 83 events were reported to have occurred in and around Egypt and to have caused damage of variable degrees in different localities. *Kebeasy et al. (1981)* reported 12 moderate earthquakes ($5.0 < M < 7.0$) which were reported to have caused significant damage in the densely populated areas of northern Egypt during the last thousand years.

The seismicity of Egypt is characterized by a moderate earthquake activity due to the relative motion between the African, Arabian and Eurasian plates *(Abou Elenean et al., 2009)*. Figure 2 shows the main tectonic trends affecting Egypt and East Mediterranean. The general distribution of earth-

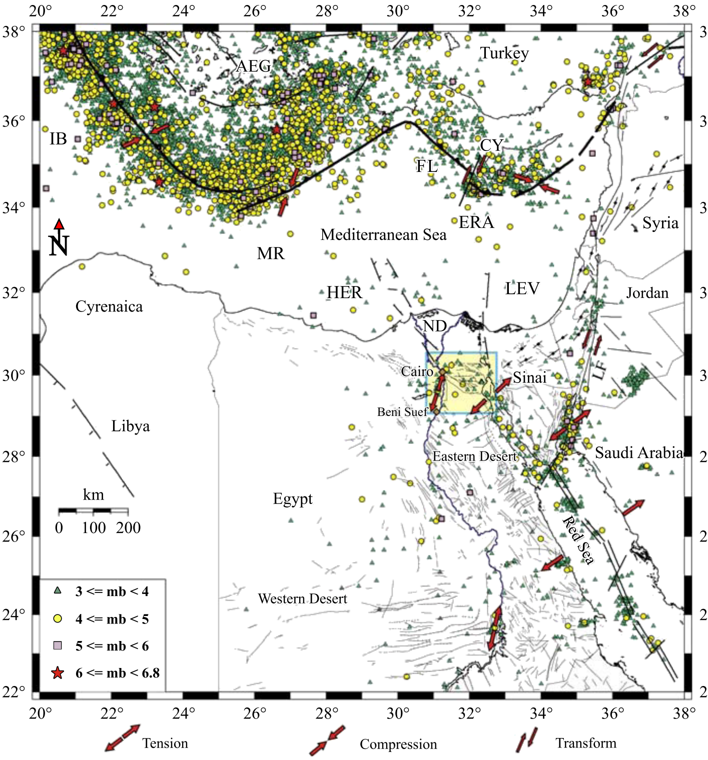

Fig. 2. Tectonic boundaries of Egypt and Eastern Mediterranean Region *(Abou Elenean et al., 2009)*. The following Acronyms represent: AEG Aegean; CY, Cyprus; ERE, Eratosthenes Seamount; FL, Florence; HER, Herodotus Basin, IB, Ionian Basin; MR, Mediterranean Ridge; LEV, Levantine Basin; LF, Levant Fault; ND, Nile Delta.

quake epicenters in Egypt falls along three major trends *(Kebeasy, 1990)*. The first major trend extends from the northern Red Sea area and along the Gulf of Suez, through the cities of Cairo and Alexandria. The second trend extends from the eastern Mediterranean to Cairo and Fayum region. The moderate earthquake of October 12, 1992 (Mb = 5.9) occurred on the intersection between the first trend and the second one near Cairo city *(Kebeasy, 1990)*. Along the third trend (Dead Sea-Aqaba trend), the seismic activity is large. This may be related to the active sinistral movement along the Dead Sea Fault system and the Gulf of Aqaba *(Reilinger et al., 1997)*. Figure 3 shows the seismic activity of the northern part of Egypt as well as the study area during the periods of gravity measurements (1997–2007). The

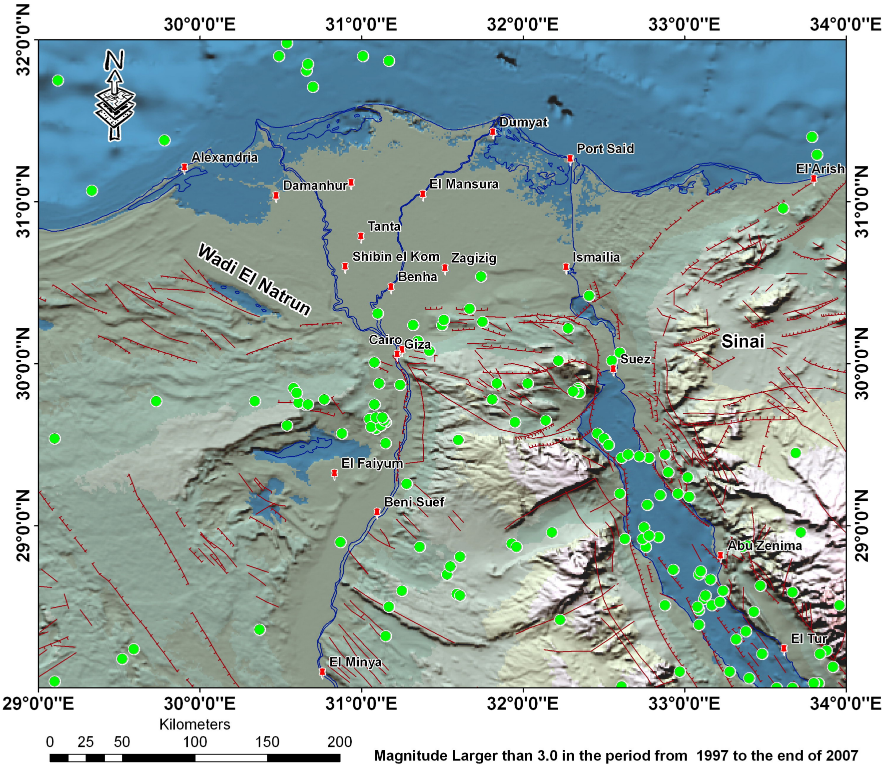

Fig. 3. Seismicity around the study area during the period 1997–2007 *(ENSN, 2008)*. Green circles refer to the magnitudes more than 3 Mb.

figure focuses on the earthquake magnitudes which are more than 3 Mb.

2. Gravity and geodetic network around Cairo

The precise gravity measurements around Cairo and the southern part of the Delta were started in 1996 on the geodetic network after the occurrence of the October 12, 1992 earthquake ($M_b = 5.9$) to study the crustal deformation behavior of the area. The network consists of 11 geodetic stations which were distributed in different localities to cover the area according to geological and seismological interest (Fig. 4). The initial measurements were carried out in April 1996 and were repeated successively till 2007.

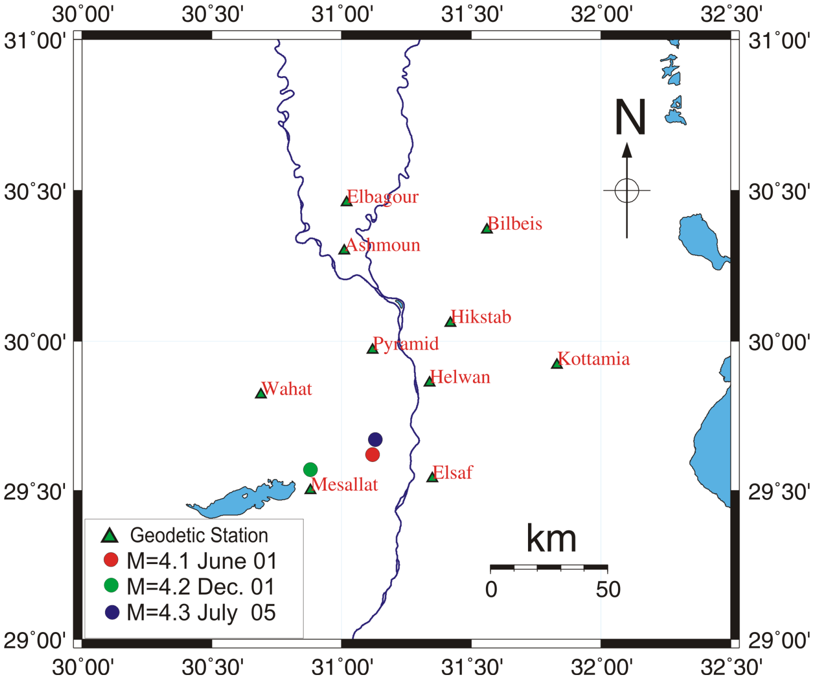

Fig. 4. Configuration of Gravity-Geodetic Network around Cairo.

3. Field procedure and data processing

The gravity measurements were carried out on the gravity network using Lacoste & Romberg (LCR) gravity meter models G1043 (LCR) (accuracy of 10 μGal) and D218 (LCR) (accuracy of 1 μGal) which belong to the National Research Institute of Astronomy and Geophysics, Helwan, Egypt. The gravity measurements were performed in parallel to the GPS measurements for the all epochs of observations. The ties between the gravity Stations of the network were measured 5 times (i.e. every station was measured 3 times) for different gravity campaigns (2000, 2004 and 2007). The precision of measurements on the selected loops ranged between 6 and 8 μGal for LCR of model D and 14–16 μGal for the LCR G model (Table 1). Then, the network was adjusted by keeping the closure error very close to zero for the respected polygons.

Table 1. Table shows the range of precision of gravity measurements of the network around Cairo and Southern part of Delta

Precision in μGal/Campaigns	2004	2007
G1043	15.2 μGal	14.4 μGal
D218	7.6 μGal	6.4 μGal

The gravity measurements were corrected for all known gravity corrections using the most advanced softwares with special interest for the drift, tides and atmospheric corrections which are very significant for precise gravity measurements. *Geosoft's Oasis montaj software* version 7.2 which belong by license to the National Research Institute of Astronomy and Geophysics, Helwan, Egypt, was used for Data analysis and processing. The absolute values of the station are calculated relative to Helwan absolute gravity station. Then, the relative gravity differences related to a fixed station (Helwan Station) were determined for the epochs 2000–2004 and 2004–2007. Figures 5 and 6 show the temporal gravity variations between the successive epochs of measurements (2000–2004 and 2004–2007).

The period of 2004 showed an increase in gravity values related to 2000 for the stations representative for Southern part of the net. The maximum change was reported for the pyramid geodetic station (41 μGal). The Northern part of the net showed a decrease in gravity values for the same period of measurements. The minimum change is noticed at the Kottamia geodetic station ($-41\,\mu$Gal) (Fig. 5). An opposite behavior was noticed during the last epoch of measurements (2007). The gravity values showed negative changes related to 2004 for Southern part of the net. The minimum decrease reaches $-50\,\mu$Gals at the pyramid geodetic station. Also, the gravity values showed positive changes related to 2004 for Northern part of the net. The maximum change reaches $49\,\mu$Gal at the Kottamia geodetic station (Fig. 6).

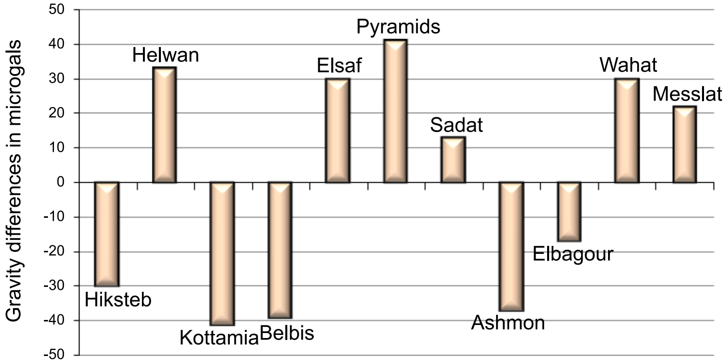

Fig. 5. Figure shows the gravity changes in microgals between the periods 2000–2004.

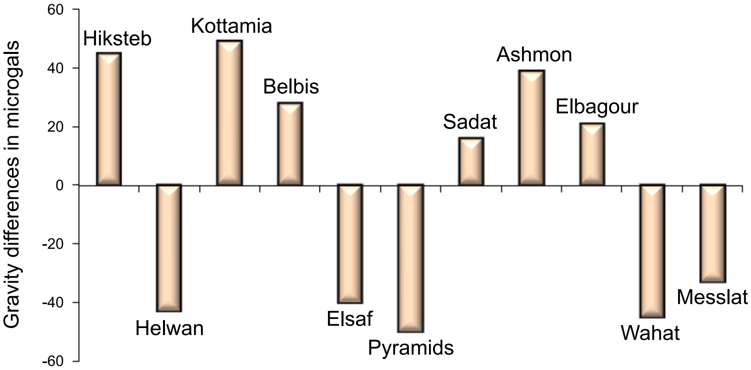

Fig. 6. Figure shows the gravity changes in microgals between the periods 2004–2007.

4. Gravity changes and earthquake activity

The temporal gravity changes were correlated with the observed earthquake activity during all periods of observations. It was found that there is a certain relation shown by increasing gravity values before the main seismic activity. In this relation, we concentrate on the seismic events with magnitudes more than 4.

The group of stations (Helwan, Pyramid, Elsaf, Wahat, and Messlat) showed an increase in gravity values especially between last epochs of measurements (1998–2000) *(Badawy et al., 2002)*. This increase could be due to elastic effects in response to pre-seismic strain changes or accumulation due to Dahshour earthquakes of June 2001 and Dec. 2001 with magnitude of 4.1 and 4.2, respectively. Figure 5, which represents the gravity changes between epochs 2000–2004, shows a similar behavior for this group of stations representative for the Southern part of the network. This behavior can be noticed by positive changes of gravity values measured in 2004 as compared with measurements of 2000. This behavior could be explained by compressive deformation and strain accumulation stage before the Southwestern Cairo earthquake of July 31, 2005 with magnitude of 4.3.

The relatively low amplitude of positive gravity changes between measurements of 2000–2004 compared with the positive changes between campaigns of 1998 and 2000 may be due to the effect of the two events (Dahshour earthquakes of June 2001 and Dec. 2001), i.e. the cause of this relatively low positive signal is associated with the presence of decreasing gravity values between 2000 and 2004 due to the stress release after Dahshour earthquakes of June 2001 and Dec. 2001. This decrease is not noticeable as it is compensated by pre-seismic strain accumulation of the Southwestern Cairo earthquake of July 31, 2005 with magnitude of 4.3. The resultant gravity change in the measurements of 2004 is small and positive for the stations closed to the epicentral area.

For the gravity campaign of 2007, the result of measurements showed a considerable decrease in gravity values when compared with the measurements of 2004 (Fig. 6). These negative changes can be interpreted by the effect of stress release stage after the earthquake of July 31, 2005. Figure 7 represents an example for the relation between non-tidal gravity changes and seismic activities for one of the network stations (Helwan) during the

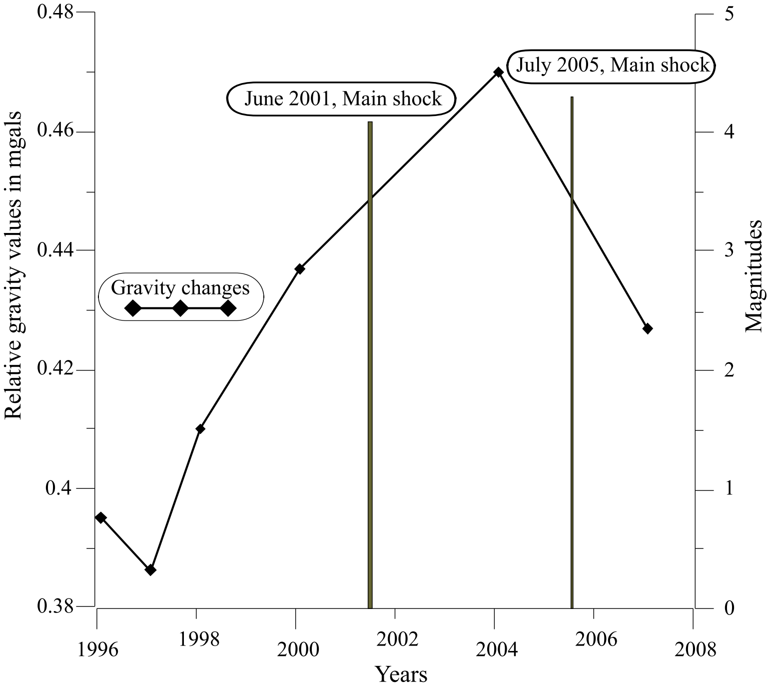

Fig. 7. Figure shows the relation between gravity changes and earthquake activity. Helwan station is chosen as an example for this relation.

periods of gravity measurements. Despite the existing noticeable relation between the earthquake occurrences and gravity field changes form the gravity campaigns of 2000–2004–2007, due to the small number of observations we assume there is rather a relation between gravity changes and continuous deformation process, than a direct relation to earthquake occurrence. However, the limited number of campaigns has not allowed yet developing a model of such relation.

5. Geodetic changes

The magnitudes of the horizontal velocity vary between 4 and 8 mm/year, with an average value of 5.15 ± 1.1 mm/year. The stations are relatively moved in the Northwest direction *(Abdel-Monem et al., 2008).*

For the period from May 2004 to Sep. 2007 it is noticed that the maximum shear strain is minimized and the rate varies between 0.02 to 0.38 microstrain (Fig. 8) *(Abdel-Monem et al., 2008).* Otherwise, the rate of the maximum shear strain is still in its maximum value towards the northern-eastern part and reached its lowest rate towards the south. In the northern-western part it reached the maximum value rather than in the other parts of the network, where its rate is 0.38 microstrain. These results typically coincide with results deduced from temporal gravity variations and seismic activity of the area.

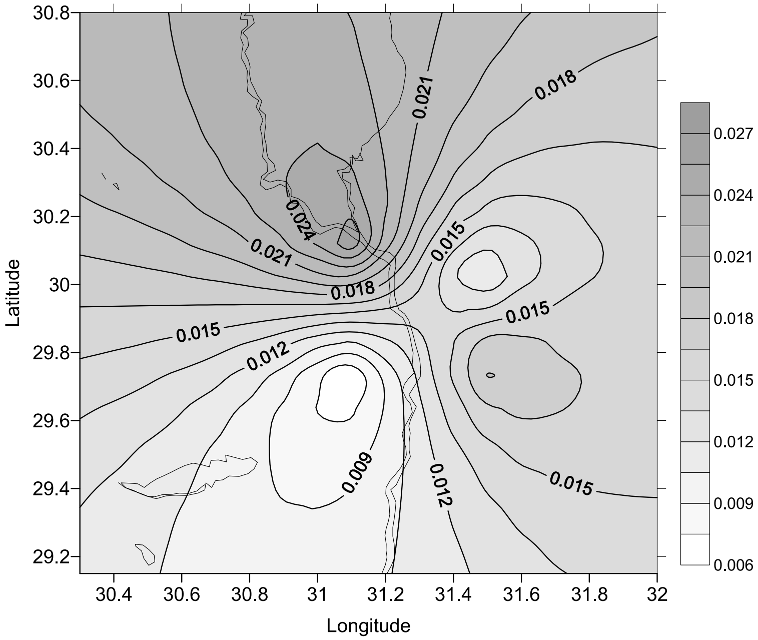

Fig. 8. Map represents the maximum shear strain values of the study area *(Abdel-Monem et al., 2008).*

6. Conclusions

Studying the temporal gravity variations for the area of Greater Cairo and

Southern part of the Delta yielded some results which can be summarized in the following:

1. The maximum positive amplitude was reported for the period of 2004 at the pyramid geodetic station (41 μGal) Southern part of the net. The minimum negative amplitude ($-41\,\mu$Gal) was recorded at Northern part of the net in Kottamia geodetic station.
2. In contrary, the gravity values showed negative changes compared to 2004 for Southern part of the net. The minimum decrease reaches $-50\,\mu$Gals at the pyramid geodetic station. Also, the gravity values showed positive changes related to 2004 for Northern part of the net and maximum positive amplitude are 49 μGal at Kottamia geodetic station.
3. The correlation between temporal gravity variations and seismic activity for the study area approved that there is a certain relation characterized by increasing gravity values before the main seismic activity. The positive changes of gravity values of 2004 related to measurements of 2000 could be explained by compressive deformation and strain accumulation before the Southwestern Cairo earthquake of July 31, 2005 with magnitude of 4.3.
4. Also, and in the same way, the negative changes recorded during the gravity campaign of 2007 can be explained by a stress release after the main shock of July 31, 2005.
5. Due to the small number of observations, we assume there is rather a relation between gravity changes and continuous deformation process than a direct relation to earthquake occurrence. However, the limited number of campaigns has not allowed yet developing a model of such relation.
6. The results of geodetic measurements during the period of gravity measurements (maximum shear strain values and distributions) typically coincide with results deduced from temporal gravity variations and seismic activity of the area.

Based on the results obtained, we strongly recommend for further gravity campaigns to give more clear view about the geodynamics of the study area and take into account, the relation between gravity changes and seismic activity.

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