

SHORT COMMUNICATION

GPS DERIVED VELOCITY AND CRUSTAL STRAIN FIELD IN THE VICINITY OF CAIRO CITY, EGYPT

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Five years of Global Positioning System (GPS) measurements (1996–2000) are used to derive velocity vectors, strain field and principal components of strain in the vicinity of Cairo city, Egypt. Estimated horizontal velocity vectors in ITRF96 are in the range of 20–27 mm/yr with an average of 24 mm/yr in $N4^{\circ}\pm5^{\circ}W$. Least-Squares prediction (LSP) technique is used to estimate the dilatational strains, maximum shear strains, and principal axes of strains. The important features are: (1) dilatational strains show that the northern part of the region is under a compressive strain regime, (2) maximum shear strains show good agreement with the recent crustal activities, (3) principal axes of the strains indicate that the compressional force acting at the convergent plate boundary between the Eurasian and the African plates affect the southern part of the Nile Delta and (4) the principal axes of strains show a good correlation with the S_{Hmax} directions obtained from earthquake focal mechanisms and bore-hole breakouts.

Introduction

The Global Positioning System (GPS) is a space based navigation system consisting of a constellation of 24 satellites, in six orbital planes with 55° inclination to the equator. The satellites are placed at a height of about 20,200 km with 12 hours orbital period and are operated by the United States Department of Defense (DOD) for accurate determination of position, velocity and time. All the GPS satellites are controlled by system tracking stations, ground antennae and the master control station (Hofmann et al 1994). The positional accuracy that can be estimated depends on our ability to account for various error sources (Reddy, 2001).

Crustal deformation studies have received new impetus all over the world with the full complement of satellites for adequate coverage, availability of comparatively low-cost

receivers, sophisticated post processing softwares and international cooperation through International GPS Services for Geodynamics (IGS). The methodology used to estimate changes in position coordinates and baseline lengths in three orthogonal directions computed with GPS data during successive visits, enable some to assess the crustal deformation. Changes in deformational rates have intrinsic value in understanding the physics of the earthquake processes.

In many countries, the receivers are used permanently in a network mode with data telemetered and processed continuously to have upgraded baseline vectors regularly. For the past few years, regional GPS networks, designed mainly to monitor strain for earthquake research and forecasting have been operated in many countries all over the world and have proved useful in detecting the crustal displacements.

In Egypt, the Cairo city region has been the focus of intense geological and geophysical investigations since the occurrence of the 12th October 1992 earthquake ($M_b=5.9$) in Dahshour city, about 25 km southwest the Cairo city. This earthquake has caused a widespread damage in Cairo city and its surrounding areas. Therefore, the National Research Institute of Astronomy and Geophysics (NRIAG), Egypt, started a series of geophysical studies in the epicentral area, in and around the Cairo city, to help in understanding the physical processes of the crust in this tectonically active area. In addition, near to the epicenter of the 1992 earthquake, two moderate but destructive earthquakes occurred in 1303 and 1847 (Badawy and Monus, 1995). In this paper, GPS derived results on crustal deformation are presented and the discussion of their characteristics are followed.

GPS Data Collection and their Analysis

A GPS network consisting of 11 sites (Fig. 1) has been established around greater Cairo city, in 1995. The Nile

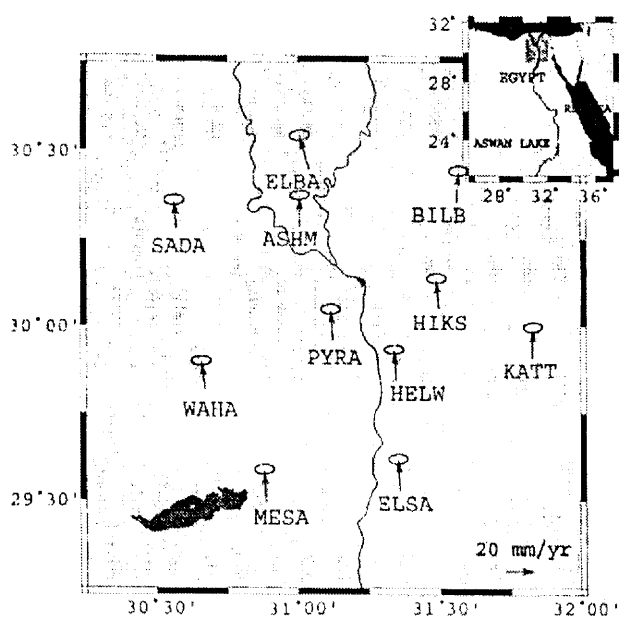


Fig.1. Velocity field estimated by repeated GPS observations with its 95% confidence ellipses in ITRF96 reference frame.

River runs in the middle of this network (Fig. 1). The northern part of the GPS network covers the southern part of Nile Delta, whereas its eastern and western parts are mainly deserts. The campaign observations have been repeated in the area each year between 1996 and 2000. The data span over five years are long enough for obtaining reliable velocities at the sites. GPS observations are carried out using dual frequency Trimble 4000SSE and 4000SSI receivers. The sampling interval and elevation were fixed at 30 sec and 15° respectively throughout the survey.

The GPS data are organized into 24 hours segments covering a UTC day to facilitate the combination of the data with some of the surrounding IGS sites; ANKR, ONSA, KOSG, IISC, BAHF, YARI, and MAS1 to constrain the site coordinates. Then, the data are processed using the GAMIT software, developed at MIT and SIO (King and Bock, 1991), to produce estimates and associated covariance matrix of station position for each station with loose constraints on the parameters. In order to get a combined solution (site positions and velocities), all such covariance matrices are used as input to GLOBK, which is a Kalman filter. The basic algorithms and a description of this technique are given by Herring et al. (1990) and its application to GPS data. By introducing global h-files, one may obtain coordinates and velocity vectors at each site in the ITRF96 reference frame. Figure 1 shows the horizontal component of the velocity vectors with 95% confidence

error ellipses. The horizontal components of these velocity vectors are further used to estimate the strain field by Least-Squares Prediction method and are discussed in El-Fiky and Kato (1999) and Reddy et al. (2000).

Results and Discussion

To estimate the crustal strains in the GPS data for the period (1996-2000), we used horizontal velocity vectors shown in Fig. 1. The averages of velocities in the NS and EW components are subtracted separately from all of the site velocities to remove systematic bias. Then, the LSP, as described above is applied to each of the vector components (East-West and North-South) independently. Empirical Covariance Function (ECF) for each of the components are fitted to the data. The parameters of k_{ii} , C_{ii} , and C_{ij} for the EW component are estimated to be 0.012 km^{-1} , $40.01 (\text{mm/yr})^2$, and $13.5 (\text{mm/yr})^2$ respectively. And the k_{ii} , C_{ii} , and C_{ij} parameters for NS component are estimated to be 0.015 km^{-1} , $12.0 (\text{mm/yr})^2$, and $3.5 (\text{mm/yr})^2$ respectively. These parameters are used to generate the covariance matrices and reconstruct displacement vectors (signal) at grid points of the study area. The estimated velocities at these grid points are then differentiated in space to obtain crustal strains in the data period.

In order to establish a common reference frame for the observational GPS campaigns, the above mentioned seven IGS stations are selected. These stations have small RMS in each velocity component i.e around 1.0 mm/yr in the ITRF96 reference frame. Note that, ITRF96 is adopting the NNR-NUVEL1 plate motion model (Patrick et al. 1998). The magnitude of the horizontal velocity vectors in ITRF96 is in the range of 20 - 27 mm/yr with an average of $24.16 \pm 2.1 \text{ mm/yr}$ in $N4^\circ \pm 5^\circ W$. The associated errors are about 3 mm and 1.5 mm in east and north components, respectively. The observed horizontal velocity vectors with error ellipses are shown in Fig.1. Direction of the estimated average velocity is consistent with that of the African plate relative to the Eurasian plate by NUVEL-1A ($N2^\circ \pm 3^\circ E$), but the velocity rate of this region is about two times greater than that estimated for the African plate relative to the Eurasian plate by the same model ($11 \pm 1 \text{ mm/yr}$ in $N2^\circ \pm 3^\circ E$ direction). The satellite laser ranging (SLR) observations near HELW (Helwan site) support the NUVEL-1A rates for northeastern Africa. The problem with the SLR observations is that the results show a greater degree of uncertainties at this station (Helwan, $6 \pm 9 \text{ mm/yr}$ at $213^\circ \pm 62^\circ$). Long span and denser GPS observations are needed to clarify the high velocity rate in this study.

Figures 2,3 and 4 depict the estimated spatial dilatational strains, maximum shear strains, and principal axes of strains,

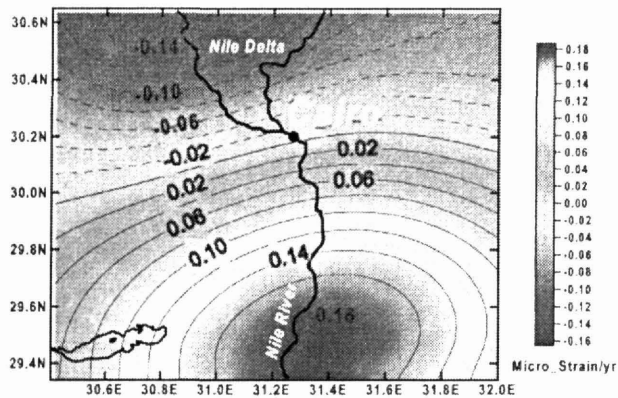


Fig.2. The rate of areal dilatation of the Greater Cairo region estimated by the LSP technique for the period from 1996 to 2000.

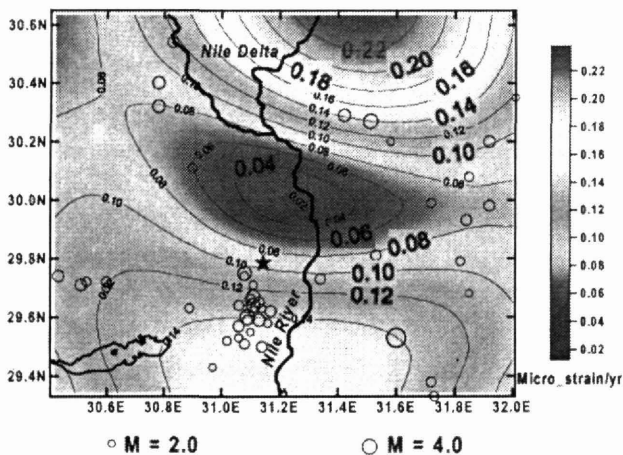


Fig.3. Distribution of the maximum shear strain rates. Shallow earthquakes ($d < 30$ km) of magnitude greater or equal to 2.0 from Jan. 1996 to Dec. 2000 are plotted (Egyptian Seismic Network and ISC). Star indicates the epicenter of the October 12, 1992 earthquake.

respectively. Although these figures are estimated only from five years of data, they well portray characteristics of the tectonic deformation in the Cairo region.

The dilatational strains shown in Fig.2, indicate that the studied region is separated into two areas: the northern part where compressional strain is predominant and the southern part where extensive spatial strain prevails. The largest compressions reaching more than 0.2 ppm/yr in the northern part may be due to the subduction of the African plate along the Hellenic arc and/or the convergent strain rate is dominant in the northeastern Africa due to the collision of Africa and Eurasia and the strain field in the northern part of Cyprian arc. El-Fiky (2000) used the velocity vectors at 189 sites derived from GPS observations in the Eastern

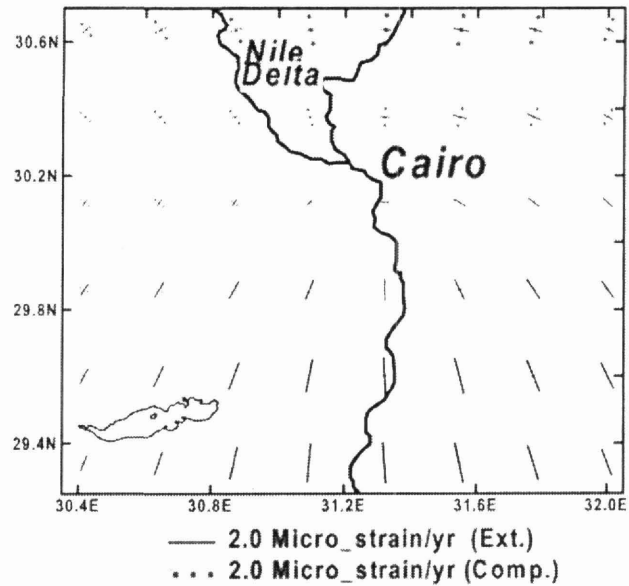


Fig.4. Magnitude and orientation of principal axes of strains. Solid and the dotted lines indicate compressional and extensional strains respectively.

Mediterranean–Middle East region for the period between 1988 to 1997 to investigate the crustal strain field in this tectonically active region. He found that the convergent strain rate is dominant in the northern Africa due to collision of Africa and Eurasia. The strain field in the northern part of the present study is in good agreement with his analysis. The present analysis also reveals that the crustal deformation due to the collision of African and Eurasian plates may be extended from plate boundary and covers the southern part of the Nile Delta. On the other hand, the large area of extensional strains seem to be in relation with the tectonic motion along the Gulf of Suez and the deformation along the NW-SE and W-E faults in this region.

Maximum shear strains, Fig.3 show two maxima of high values of strain in the northern and southern parts of the studied region separated by a very low maximum shear strains or almost strain-free zone in the middle of the region. It is interesting to note that, the southern edge of the above low area has witnessed the earthquake (October 12, 1992). We should also note that the first GPS campaign was in 1996, about four years after the October 1992 earthquake. Therefore, we may infer that the accumulated strain in this low zone was totally released by the co-seismic and the post-seismic activity of the October 1992 earthquake. In addition, the present analysis shows that there is no such evidence for earthquake activity in this low zone in the near future. However, there is still possibility for seismic activity in the northern or southern parts of

the studied area where the strain rates are high. The above low zone of strains has been confirmed by seismic data. Mohamed (2001) uses the seismic data for the period 1910-1999 and uses Richer's formula to estimate the earthquake energy release as function of time and location in and around the Cairo city. His results show that the level of earthquake activity is very low throughout the studied region, except for the Dahshour area for the period 1992-1993.

On the other hand, the strain field in the two maxima in northern and southern areas may not relate to any co-seismic and/or post-seismic movements. The seismicity of this area is happened to be very low during the period of our interest, with the largest magnitude of earthquake being recorded is less than 4.0. Comparison of the maximum shear strains with the seismic data, epicenters of shallow earthquakes of depth less than 30 km in the same region, indicates that the high strain rates in the northern and southern areas may be due to the subduction of the African plate under the Eurasian plates and the tectonic motion along the Gulf of Suez as well as the deformation along the NW-SE and W-E faults in the region. Generally, the low strain rates and low level of earthquake occurrence in the central part of the studied region (the low zone) during the present interval indicate that internal deformation in this region is very small.

The distribution of principal axes of strains (Fig. 4) show a general contraction of about 0.2 ppm/yr in nearly north-south direction in the northern part of studied region. This may be due to the compressional force acting at the convergent plate boundary between the Eurasian and the African plates. The present analysis indicates that the

effect of this force may be extended to the southern part of Nile Delta. Badawy (2001) has used earthquake focal mechanisms and bore-hole breakouts in Egypt and has compiled the stress field for Egypt including the studied region. His results show dominant NW-SE compression in and around the Cairo city and in general, show good agreement with the strain rate field derived from GPS.

Conclusions

Velocity vectors in ITRF96 obtained from six GPS campaigns during 1996-2000 indicate that the magnitude of the horizontal velocity in the vicinity of Cairo city is in the range of 20-27 mm/yr with an average of 24 mm/yr in N4°W. The estimated dilatation strain rate and the maximum shear strain rate are both about 0.12 micro strain/yr in average. A compressional strain regime is observed in the northern part of the studied region, which might be due to the collision of Africa and Eurasia. The large area of extensional strains in the southern part of the studied region may be related to the tectonic motion along the Gulf of Suez and the deformation along the NW-SE and W-E faults in the region. Maximum shear strains show two maxima of high values of strain in the northern and southern parts of the studied region separated by a very low zone of maximum shear strains or almost strain-free zone in the middle of the region. The earthquake which occurred on 12 October 1992 indicated that the accumulated strain in this low zone is totally released by the co-seismic and post-seismic activity. The principal axes of strains correlate with the S_{Hmax} directions obtained from earthquake focal mechanisms and borehole breakouts.

References

- BADAWY, A. (2001) The present-day stress field in Egypt. *Annali di Geofisica*, v 4, pp 557-570.
- BADAWY, A. and MONUS, P. (1995) Dynamic source parameters of the 12th October 1992 Earthquake, Cairo, Egypt. *Jour Geodyn*, v 20, pp 99-109.
- EL-FIKY, G. S. and KATO, T. (1999) "Interplate coupling in the Tohoku district, Japan, deduced from geodetic data inversion". *Jour Geophys Res*, v 104, pp 20,361-20,377.
- EL-FIKY, G. S. (2000) Crustal strains in the Eastern Mediterranean and Middle East as derived from GPS observations. *Bull Earthq Res Inst, Univ of Tokyo*, v 75, pp 161-181.
- HERRING, T. A., DAVIS, J. L. and SHAPIRO, I. I. (1990) Geodesy by radio interferometry. The application of Kalman filtering to the analysis of very long baseline interferometry data. *Jour Geophys Res*, v 95, pp 12561-12581.
- HOFMANN-WELLENHOPF, B., LICHTENEGGER, H. and COLLINS, J. (1994) *Global Positioning System Theory and Practice*. Springer-Verlag Wien, New York.
- KING, R. W. and BOCK, Y. (1991) *Documentation for the MIT GPS analysis software*. Mass Inst of Technol, Cambridge.
- PATRICK, S., AITAMIMI, Z. and BOUCHER, C. (1998) The ITRF96 realization and its associated velocity field. *Geophys Res Lett*, v 25, pp 3223-3226.
- MOHAMED, A. S. (2001) Seismicity and recent crustal movement studies in and around the greater Cairo region, Egypt. *Acta Geod Geoph Mung*, v 36(3), pp 353-362.
- REDDY, C. D., GAMAL EL-FIKY, TERUYUKI KATO, SEIICHI SHIMADA and VIJAY KUMAR (2000) Crustal strain field in the Deccan trap region, western India, derived from GPS measurements. *Earth Planet Space*, v 52, pp 965-969.
- REDDY, C. D. (2001) Error contributors and accuracy in GPS measurements. *Ind Geol*, v 2, pp 235-244.

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