The use of satellite laser observations in studying the crustal movements

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Abstract   The mutual tectonic displacements of the lithospheric blocks take place within the deep fracture dividing them into hundreds and thousands kilometers long. It is possible to suggest that the reason of the accumulation of considerable local shift deformations is the change of the velocity of the tectonic motion in some or other parts of fractures as a result of different physical, chemical and mechanical processes. Nowadays, the range precision of Satellite Laser Ranging (SLR) technique reaches a few millimeters level. Therefore, the space geodesy technique becomes a very important tool in detecting and monitoring recent crustal movements. Regular repeated measurements of the baselines between some stations on different plates give the possibility to construct precise and detail models of crustal movements. In this paper, the length of four baselines between Helwan-SLR station and other four SLR stations are calculated using satellite geodetical technique.
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Introduction

There are some space geodetic technologies which can deal with the tectonic motion around the world. The Satellite Laser Ranging (SLR) is one of these technologies. The mutual tectonic displacements of the deep fracture divide them into hundreds and thousands of kilometers long. It is possible to suggest that the reason of the accumulation of considerable local shift deformations is the change of the velocity of the tectonic motion in some parts of fractures as a result of different

physical, chemical and mechanical processes. Regular repeated geodetic measurements of the active zones make the possibility to study slow secular motions of the earth's crust and to reveal the places of the accumulation of elastic deformations. Methods of satellite geodesy are very effective from the point of view of monitoring deformation of the Earth's crust in global and regional scales. Changes of the length of chords between stations hundreds and thousands kilometers apart from each other detected with the use of the SLR data agree well with the plate motions models (Hauck, 1987; Attia et al., 2012; Fahim and Khalil, 2000; Chapanov Ya and Tatevian, 1990; Reilinger et al., 2006). The accumulation of the data gives a possibility to construct a precise and detail model of the global tectonics.

Geologic features and characteristics of the African continent exhibit all phenomena associated with crustal deformations, accumulation and release of crustal stress and strains, inter-plate motions as well as volcanic eruptions. Therefore, Africa has to be involved in an international geodynamics

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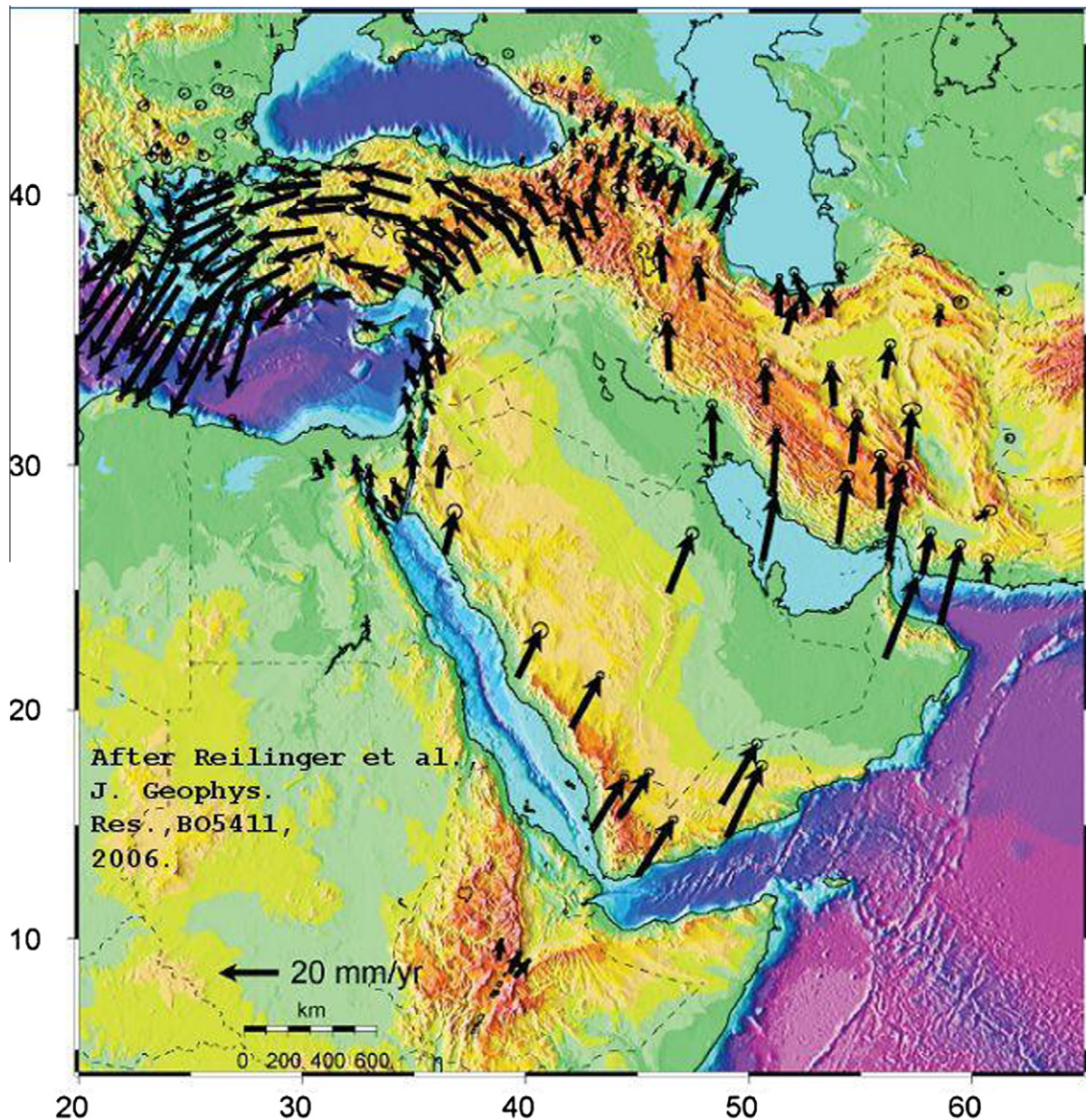 E-mail address: gamal_fahimattia@yahoo.com (G.F. Attia).

Fig. 1   The tectonic motions as clarified by Reilinger et al. (2006).

and earthquakes research programs. Fig. 1 shows the results of the GPS tectonic motion as determined by Reilinger et al. (2006). It shows that the African zone is active; hence more studies on the tectonic motions from Helwan SLR station will be important. So, in this work we will discuss the method of short-Arc and apply its algorithm for the baseline determinations from Helwan-SLR station and some other stations.

Baseline determination using the short-Arc method

The baselines are the distances and lengths of the chords between projections of the positions of the laser stations on the reference ellipsoid. For the satellite geodesy, it is very important to determine the optimal length of orbital arc along which laser measurements are to be carried out. It is clear that for the

dynamical methods long arcs (one month or more) are to be used. According to which more errors of modeling of different physical forces such as earth's gravitational field, air drag, solar radiation pressure, and others that may influence the accuracy of the estimation of the satellites position, at the same time the measured errors con be almost completely excluded and high stability in determination of relative coordinate system can be achieved. It is possible to diminish the influence of the errors of modeling by using short-arcs of the satellite orbit (several revolutions or days), but the station's coordinates estimated by different arcs con differ from each other by a larger quantity than statistical zero.

Under the semi -dynamical "short-arc" method one or several passes of the satellite in one of simultaneous visibility from both ends of the chord is known (Dictrch and Genill, 1984; Chapanov Ya and Tatevian, 1990; Tatevian, 1980). The esti-
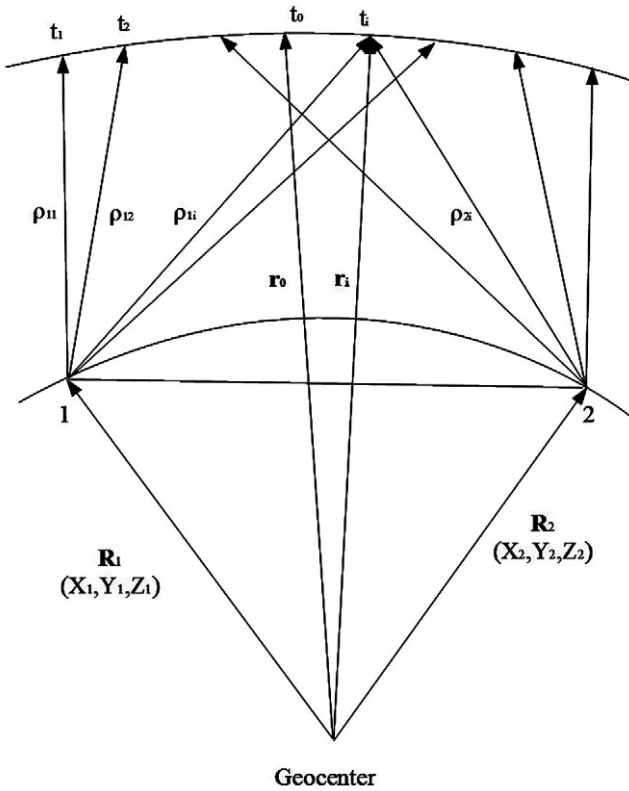
Fig. 2 Geometrical representation.

mated parameter in this case is the length of the chord as shown in Fig. 2.

The comparison of the same baselines calculated with long and short arcs methods shows a good agreement and even speaks in favor of the last one, as the number of observations required for solving the problem considerably decreases the amount of calculations.

Let laser ranging ρ_{ik}; $i = 1, 2, \ldots, n$ be carried from two stations for the same satellite's pass. We suggest that at the observation moment t_i, the radius vector r_i of a satellite in Greenwich coordinate system is known. It can be obtained using the laser ranging data from a model of perturbation forces on an interval of several days (Saroken et al., 1984).The geocentric vectors of the station $R_k(x_k, y_k, z_k)$ are to be known with sufficient accuracy. The covariance matrix of the initial parameters of the satellite's motion is Q_r, and the rectangular coordinates of the station Q_{R_K} are known.

The corrections of the estimated quantities, to the initial elements of the satellite's orbit for the mean time t_0 of the observation interval, are dr_0, dr_0'. In other words, corrections to geocentric vector r_0 and to the range rate r_0' of a satellite are corrections to the adopted values of a baseline and to the geocentric vectors of the two stations. The general form of the expression for baseline L between two points R_1 and R_2 can be written as

$$\overline{L}_{12} = \sqrt{\rho_{i2}^2 - \rho_{i1}^2 + 2\rho_{i1}L\cos(\overline{L}\rho_{i1})},$$

$$\overline{L}_{21} = \sqrt{\rho_{i1}^2 - \rho_{i2}^2 + 2\rho_{i2}L\cos(\overline{L}\rho_{i2})} \tag{1}$$

It is evident that for the case of satellite ranging from k – stations we have:

$$\rho_{ik}^2 = R_k^2 + r_i^2 - 2R_k r_i \cos(\overline{R}_k - \overline{r}_i) \tag{2}$$

After linearization of Eqs. (1) and (2) and taking into account that the approximate quantities R_k^0 and r_i^0 are known, we can write the equation of measuring corrections in the following form where ρ_{ik}^0 is the calculated distance between the station and the satellite at the moment of measurements.

$$V_{ik} = \frac{\partial \rho_{ik}}{\partial \vec{r}_o} d\vec{r}_o + \frac{\partial \rho_{ik}}{\partial \vec{r}_0} d\vec{r}_0 + \frac{\partial \rho_{ik}}{\partial L} dL + \frac{\partial \rho_{ik}}{\partial R_{12}} d\vec{R}_{12} + (\rho_{ik} - \rho_{ik}^o) \tag{3}$$

The covariance matrix $Q_{\overline{x}}$ of the estimated parameters $(dr_o, dr_0^{\bullet}, dL, dR_1, dR_2)$ is a block-diagonal

$$Q_{x_0(9,9)} = \begin{bmatrix} Q_{r(6,6)} & 0 \\ 0 & Q_{LR_1LR_2(3,3)} \end{bmatrix} \tag{4}$$

The final solution of the estimated parameters could be given from

$$\overline{x} = \left[Q_{\overline{x}_0}^{-1} + A^T Q_L^{-1} A \right] A^T Q_L^{-1} l_{ik} \tag{5}$$

As for the calculation of the vector of free terms, we have used some kind of orbital model, so for getting strict solution of system (3) and particularly for the real estimation of the accuracy of parameters, it is necessary to take into account the influence of possible systematic errors of the adopted model by including them as unknowns in common adjustment. Covariance matrix of the free terms of the Eq. (3) can be determined as; $Ql_{(n,n)} = P_{(n,n)}^{-1} + B_{(n,9)} Q_{(9,9)} B_{(9,n)}^T$

where $P_{(n,n)}^{-1}$ is the weight of observation, while B and Q have the following form;

$$B = \left(\frac{\partial \rho_{ik}^0}{\partial \overline{r}_0} \frac{\partial \rho_{ik}^0}{\partial \overline{r}_0} \frac{\partial \rho_{ik}^0}{dR_0} \right), \text{ and } Q = \begin{pmatrix} Q_r & 0 \\ 0 & Q_{R_k} \end{pmatrix}$$

Fig. 3 The SLR observatory network.

Table 1 Baselines determinations between Helwan SLR station and some other SLR stations.

Stations	MJD	Baseline length L (m)	RMS (m)
7831–7840	50266.784425	3429766.4070	0.019
7831–7810	50264.754674	2771788.8583	0.021
7831–7939	50264.757669	1780653.3904	0.027
7831–7835	50266.795464	2634229.0854	0.023

Results and discussions

Using the algorithm method mentioned before, a computer program has been prepared for the baselines determinations from the laser ranging data. The used data are produced from the satellites Lageos-1 which have been observed during the year 1996 from the Helwan-SLR station and other SLR stations. The stations used in addition to the Helwan SLR station (7831) are, Heslmonseux (7840), Zimmerworld (7810), matera (7939) and Grasse (7835) as shown in Fig. 3. The short arc method does not depend on the dynamical models so strongly, however, in order to realize millimeter level baseline precision.

The resultant data of the normal points of satellites Lageos-1, observed during the year 1996, from Helwan station are used to estimate four different baselines. The baselines between the Helwan station and the other stations are computed and the results are shown in column 4. The first column represents the ID of the used Helwan station, column 2 represents the used time in modified Julian date, column 3, represents the value of the baseline length in meter units, as the last column shows the root mean square value of the measurements. From the analysis it is clear that the root mean square errors of the calculated baselines are within 3 cm as shown in Table 1. Anyhow, for determination of the relative motion between the African and European plates, it is necessary to calculate the same baselines for many years. This study will be our duty in other coming work.

4. Conclusion

In this research, the method used for the determination of the baselines using the short-arc method is explained. This method is applied for the determination of the baselines between the Helwan SLR station and other four SLR-stations, using the basis of SLR data. The accuracy of the determination of the baselines is found to be within the range of 3 cm, which is in agreement with the plate motions models.

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