



Monitoring of global geodynamic processes using satellite observations



S.K. Tatevian ^a, G.F. Attia ^b, N. Abou-Aly ^b, R. Ghoneim ^{b,*}, M. Hegazy ^b

^a *Institute of Astronomy of Russian Academy of Sciences, (INASAN), Moscow, Russia*

^b *National Research Institute of Astronomy and Geophysics, (NRIAG), Cairo, Egypt*

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Abstract To study mechanisms of destructive geodynamic phenomena including determination of places of possible severe earthquakes, volcano eruptions and some other natural hazards, it is important to have means to evolve areas where maximum changes of the displacement velocities and the terrestrial crust vertical movements are possible. The previous experience has shown that the satellite geodesy techniques including global navigation systems and satellite laser ranging are the most effective for research activities in this field. Permanent control of secular movement of GPS-stations of the international geodynamic network, located in Russia, has allowed improving the reference coordinate frame for North Eurasia since Russian network stations provide representative covering of the largest stable areas (the Siberian and the East European) of the Eurasian plate. Along its southern border, there is a zone consisting of a great number of microplates surrounding the South-Eurasian stable plate. Interaction of these small plates and blocks influences distribution of seismic stresses in internal parts of the continent that is confirmed by the highest seismic activity of the triangle bordered by thrusts of the Himalayas and faults of the Pamirs, the Tien-Shan, the Baikal and the North-Eastern China.

One of the active tectonic zones of Egypt located in Aswan, is characterized by regional basement rock uplift and regional faulting. In 1997, the African Regional Geodynamic Network was developed around the northern part of Lake Nasser, consists of 11 points, on both sides of the Lake. Its main goal is to study the geodynamical behavior around the northern part of the lake. The collected data were processed using the Bernese software version 5.0. From the velocity results, including also the African plate motion, it can be noticed that all stations of this network are moved to the northeast direction and it is typically the direction of the African plate motion.

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* Corresponding author. Tel.: +20 1222525944.

E-mail address: rmfg66@hotmail.com (R. Ghoneim).

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1. Introduction

Plenty of new information about the Earth and the near-Earth environment has been obtained by indirect way (as distinct from direct measurements from a satellite's board) as a result of processing of data of systematic earth-based observations

allowing to record changes of satellites' orbits. Since an artificial satellite circles the Earth and is in its gravitational and magnetic fields, then all results of detailed explorations of its orbital motion have very direct relation to understand physical and dynamical properties of the near-Earth environment and the planet itself. An important advantage of this new space branch in the field of Earth's sciences is its global nature in particular. The space geodesy allows connecting islands with continents, combining geodetic networks of the continents through oceans and seas, and measuring the Earth's planetary parameters. Theoretical fundamentals and engineering equipment of the space geodesy have been developing very dynamically for the last 50 years. The considerable increasing of satellite laser ranging accuracy in the space geodesy and fast development of radio satellite navigation systems such as GPS (USA) and GLONASS (Russia) have fully changed the approach to problems of determination of dynamic and physical properties of the Earth, as a planet (Tateviyan, 2010).

The relative coordinates of the ground-based points of the global reference network of the IERS (Fig. 1) and the base lengths at distances of hundreds or thousands kilometers are determined with errors of few mm horizontally and less than 1.0 cm vertically.

An important problem, being solved currently only by means of satellite observations and very long baseline radio interferometers (VLBI), is registration and monitoring of short-period variations of the Earth's rotation speed and its orientation in the space, since these parameters determine the Universal Time and are required to connect the inertial (celestial) frame with geocentric (terrestrial) frame. The International Earth Rotation and Reference Systems Service (IERS) Altamimi et al., 2002 regularly determines and publishes information about the Earth's orientation parameters to within 0.1–0.2 ms of the arc (1 cm) in the pole position and about 0.3 mc in time with resolution of 1 day and less (Table 1).

Coefficients of nutation (characterizing movement of the Earth's rotation axis in the inertial frame) have been determined to high precision that is necessary to study the Earth's internal structure and free nutation of its liquid external core.

Table 1 Precision of the earth rotation parameter estimation.

Years	$\sigma(X)$ 0.001	$\sigma(Y)$ –	$\sigma(UT1)$ –	$\sigma(\psi\delta)$ –	$\sigma(\epsilon\delta)$ –
		0.001	0.0001s	0.001	0.001
1962–1967	30	30	20	–	–
1968–1971	25	25	17	–	–
1972–1979	11	11	10	–	–
1980–1983	2	2	3	2	1
1984–1989	.40	.40	.20	.5	.2
1990–2000	.20	.20	.20	.3	.1
2001–2005	.15	.15	.1	.3	.1

Interpretation of long-period fluctuations of the Earth's rotation velocity (day duration) and periodical movements of the Earth's center of masses must be probably connected with generation of perfect models of the planet internal structure. These researches go on as observed material is accumulated.

The Earth's gravitation field, before 1957, was known to be accurate within the third harmonic coefficient of the gravity potential model, i.e. accurate within the Earth's flattening (1/298). The new gravity models, developed with the use of satellite observations, contain more than 150 gravity potential harmonic coefficients. This means that the external form of our terrestrial globe has become known hundreds times better than before 1957 due to the satellite geodesy.

The recent detailed models of the gravity field, obtained with the use of space missions CHAMP, GRACE, GOCE, allow discovering fine peculiarities of the Earth's tectonic structure, which have not appeared before in global satellite models (Rummel and Foeldvary, 2006). These peculiarities are the consequence of various geophysical processes in active tectonic zones of subduction, collision and plate expansion such as, for instance, the Himalayan–Tibetan Region and the Middle-Atlantic Ridge. In so far existing geopotential models, the subduction zones have appeared only as spacious areas with high gravity anomalies due to mass volume increase when shift of the terrestrial crust strata under volcanic arches occurs. More

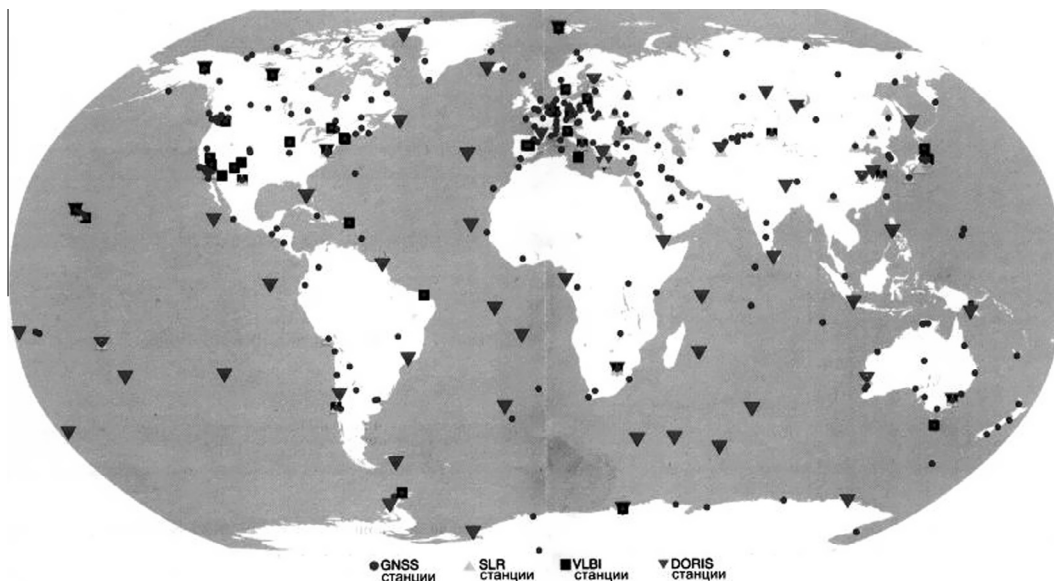


Fig. 1 Global network of observation sites of the International Earth Rotation and Reference System Service (ITRF).

detailed peculiarities of the tectonic structures could be discovered only with the use of very expensive local gravimetric measurements by means of land-based facilities or from sea vessels.

2. Studies of the tectonic movements

To study mechanisms of destructive geodynamic phenomena including determination of places of possible severe earthquakes, volcano eruptions and some other natural hazards, it is important to have means to evolve areas where maximum changes of the displacement velocities and the terrestrial crust vertical movements are possible. Since these displacements appear at the level of centimeters or even millimeters the measurement accuracy has to be proper one. The experience of the last years has shown that currently the satellite geodesy technique including global navigation systems (GNSS) and satellite laser ranging are the most effective (as for accuracy and cost-effectiveness) for research activities in this field. With the help of these measurements, quantitative data have been derived for the first time, that confirms the theoretical model of global and regional tectonic movements and displacements (Figs. 2 and 3), which are direct indicators of contemporary dynamic processes in the terrestrial crust and the mantle, and which could not have quantitative evaluation within short time intervals hitherto.

Permanent control of secular movement (velocities) of GPS-stations of the international geodynamic network, located in Russia (Fig. 4), has allowed improving the reference coordinate frame for North Eurasia since Russian network stations provide representative covering of the largest stable areas (the Siberian and the East European) of the Eurasian plate. It has been also shown per GPS measurements in the frames of local networks, that the Eurasian tectonic plate is not a monolithic tectonic block (Outkin, 2002). Along its southern border, there is a zone consisting of a great number of microplates surrounding the South-Eurasian stable plate (Fig. 5). Interaction of these small plates and blocks influences distribution of seismic stresses in internal parts of the continent that is confirmed by the highest seismic activity of the triangle bordered by thrusts of the Himalayas and faults of the Pamirs, the Tien Shan, the Baikal and the North-Eastern China.

In Egypt, one of the active tectonic zones is located in the Aswan area, which is characterized by regional basement rock

uplift and regional faulting (Gatinsky Yu and Rundquist, 2004). Local faults are supreme passed on essentially fault-lying structure of the Nubian plain and Sinn El-Kaddab plateau of Lake Nasser, (Issawi, 1968), as well as to the east of the Lake on Aswan hills as shown on Fig. 6. East of the River Nile, folds and faults are typically trending northwest having an acute angle to the primary structural upward. The northwest-trending faults are generally less than 50 km long, although some of them approach 100 km. Faults in the study area are subdivided into two systems depending on their trending directions: East–West fault system, which may considered the most active for seismicity studies, namely – Southwestern Egypt (Kalabsha and Sayal faults), and North–South fault system (Kurkur and Khor El-Ramla faults). The largest of Aswan earthquakes occurred on 14 November 1981. This earthquake had a magnitude of $M_b = 5.6$ (Kebeasy et al., 1982) and was significant, because of its possible association with Lake Nasser. In 1997, the African Regional Geodynamic Network (ARGN) was developed around the northern part of Lake Nasser, it consists of 11 points, on both sides of the Lake Nasser. The main goal of this geodetic network is to study the geodynamical behavior around the northern part of the lake. This network observed twice a year, and in this work three GPS campaigns, December 2010, November 2011 and January 2012, were selected to throw light upon the pre- and post-seismic displacements associated with the November 2011 earthquake of magnitude 4.2. The collected data were processed using the Bernese software version 5.0 (Dach et al., 2007). Precise orbits from the IGS were used throughout the processing and all the network solutions are constrained solutions with respect to station MNAM (station inside the network).

From the velocity results, including also the African plate motion (McClusky et al., 2000, 2003), it can be noticed, that all stations of this network are moved to the northeast direction and it is typically the direction of the African plate motion. (Fig. 7).

3. Global Geodetic Observation System (GGOS)

Understanding that further improvement of the contemporary International Terrestrial Reference Frame (ITRF), developed by the IERS, could be possible only with the more dense and equally distributed tracking networks and special space

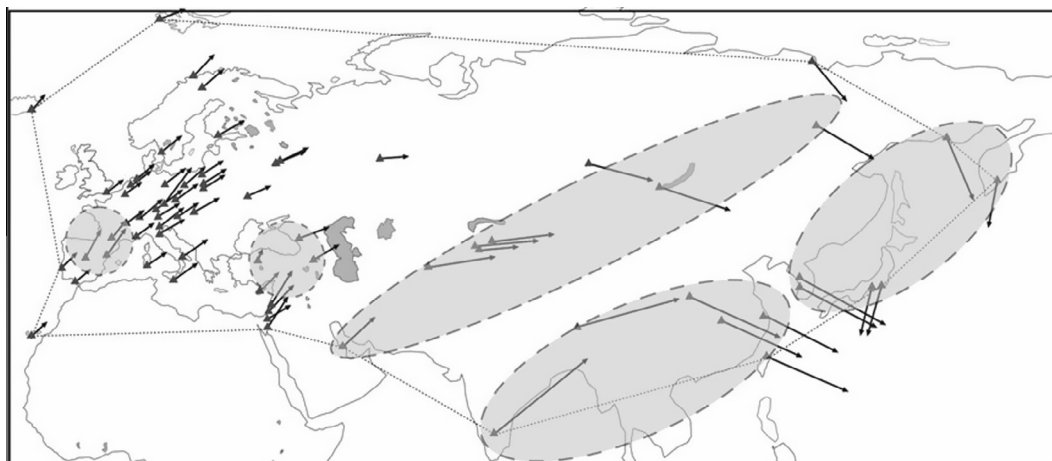


Fig. 2 Zones of sharp changes of tectonic velocities in Euroasia.

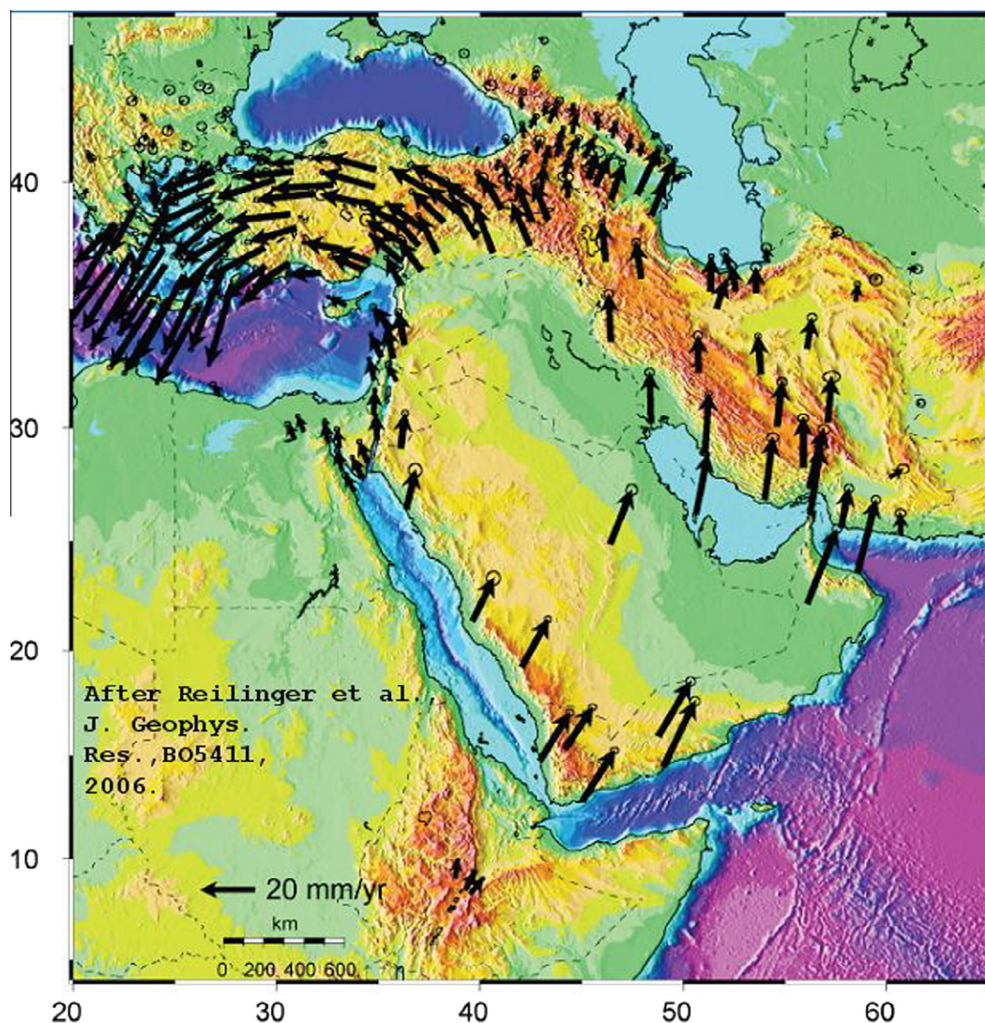


Fig. 3 Velocities (vectors of station movements), derived by space geodetic measurements (Reilinger et al., 2006).

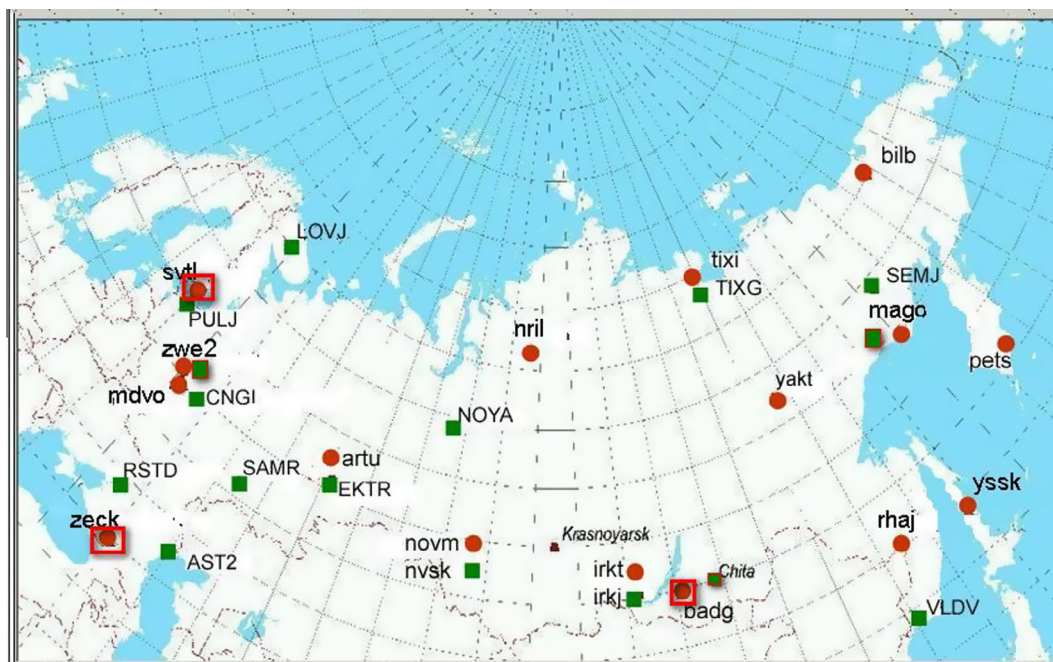


Fig. 4 GPS/GLONASS permanent sites in Russia.

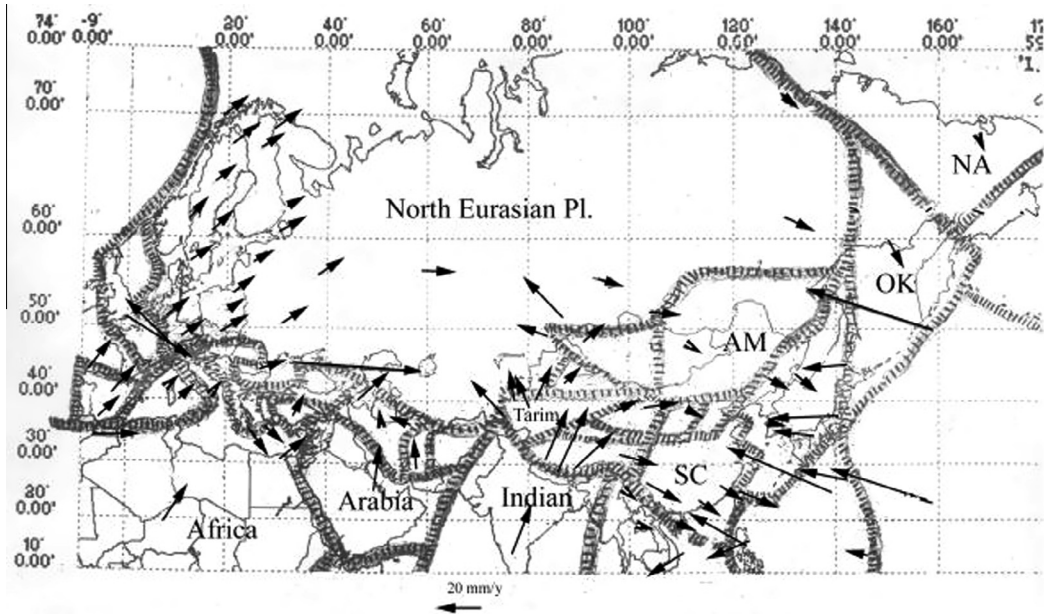


Fig. 5 Southern border of the Eurasian tectonic plate (micro plates and tectonic blocks).

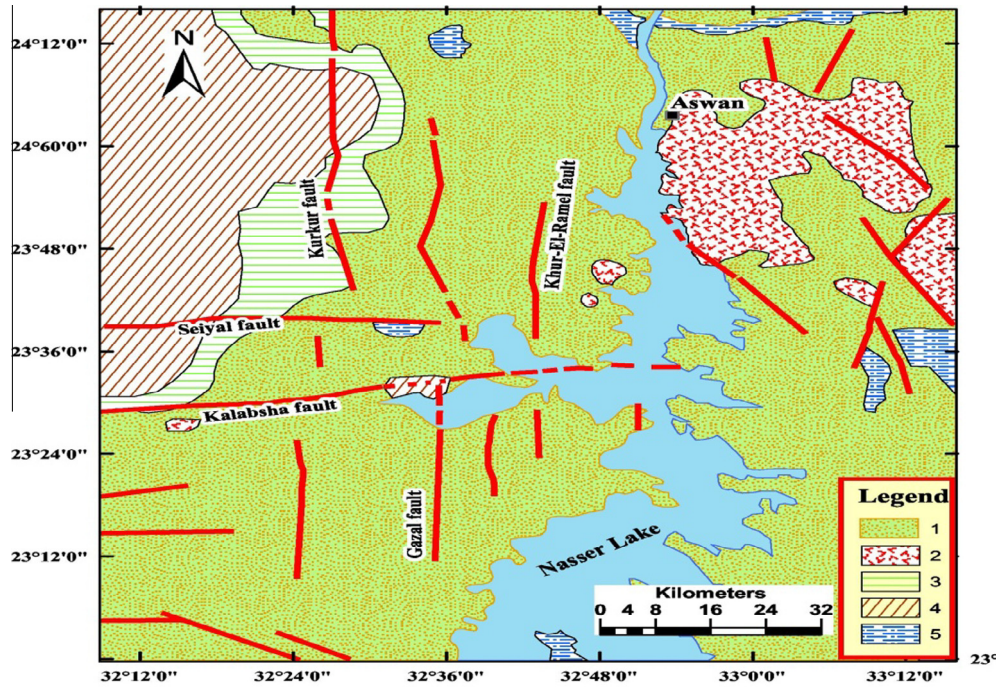


Fig. 6 Geology (Lithological and Structure) of Aswan Region, Egypt (Woodward Clyde Consultants, 1985).

missions, the International Association of Geodesy arrived to a decision on the development (by 2020) of the Global Geodetic Observing System (GGOS) (Rothacher et al., 2008). GGOS will integrate different geodetic techniques, different geophysical models, different ideas and methods in order to

ensure a long-term monitoring of the geodynamic phenomena and geophysical parameters, in agreement with the Integrated Global Observing Strategy. GGOS will consist of about 40 permanent ground tracking sites, equipped with different types of modern instruments for minimizing systematic errors,

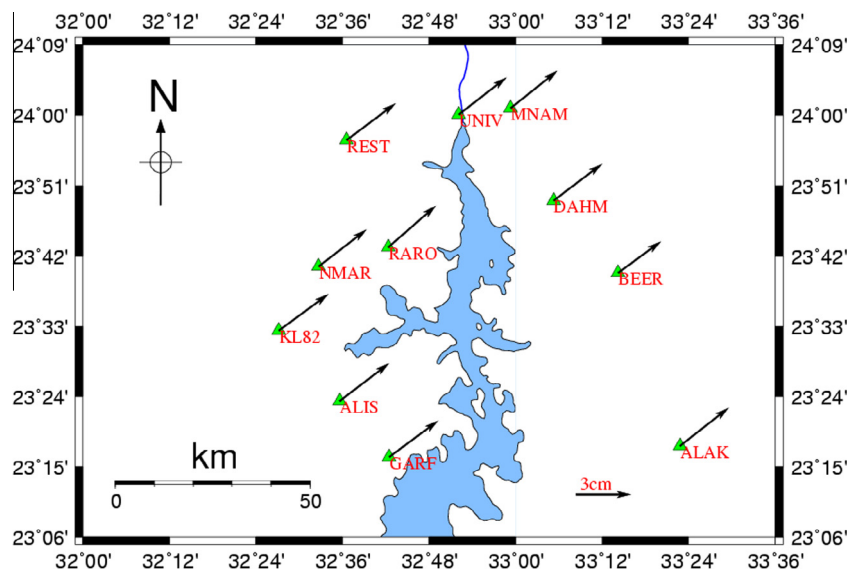


Fig. 7 The computed annual horizontal velocity of Aswan network including the African plate motion.

characteristic for every usable technique, space segment of special research satellites and centers of merging, storage and analyses of the data. There are five levels of objects, which will be observed in GGOS:

- Level 1: the terrestrial geodetic infrastructure.
- Level 2: the LEO (Low Earth Orbiter) satellite missions.
- Level 3: the GNSS and the Satellite Laser Ranging (SLR) satellites.
- Level 4: the planetary missions and geodetic infrastructure on planets.
- Level 5: the stars and extragalactic objects.

This system has to provide the observational basis to maintain a stable, accurate and global terrestrial reference frame, to link it to the celestial reference frame and to monitor the Earth's kinematics and dynamics. In this function GGOS is crucial for all Earth observations and many practical applications. In the frame of GGOS, the Earth's system is viewed as a whole including the solid Earth as well as the fluid components (atmosphere, oceans, ground waters), the static as well as time-varying quantities.

4. Conclusion

Given in these results refer to just a small part of geodynamical and geophysical researches, for which the satellite geodesy gives unique measurement data. This includes study of the mean sea level changes and the ground water volume fluctuations that is directly related to the global change of the planet climate. Mass transfer and changes in the Earth interior induce small, but significant changes in the shape, rotation, and orbital motion of the Earth. Precise measurements and control of these relatively small changes are essential for a variety of applications, as well as for understanding the behavior of the Earth's interior and its influence on Volcanic and seismic activities. In this connection, the most important task of space geodesy is a development of the global terrestrial reference coordinate frame, accurate and stable within sub-centimeter

level. Such a frame relies on the diversity of surface-based and space-based observations, which are possible through the long-term worldwide cooperative efforts. From this point of view it is very important to densify the network of GNSS sites in the eastern part of African continent and in active geodynamic area near Aswan.

References

- Tatevian, S.K., 2010. Monitoring of the Global Geodynamic Processes by the use of Satellite Observations. In: Contant, J.-M. Menshikov, V.A. (Ed.), *Space for Security and Prosperity of the Peoples*, IAA, pp. 391–400.
- Altamimi, Z., Sillard, P., Boucher, C., 2002. ITRF2000: a new release of the International Terrestrial Reference Frame for Earth's science applications. *J. Geoph. Res.* 107(B10), 221. doi:10.1029/2001JB000561.
- Rummel, R., Foeldvary, L., 2006. Mission simulation and semi-analytical gravity field analysis for GOCE SGG and SST. In: Flury, J. et al. (Ed.), *Observation of the Earth System from Space*, Springer Verlag, pp. 193–208.
- Robert Reilinger¹, Simon McClusky¹, Philippe Vernant¹, Shawn Lawrence^{1,17}, Semih Ergintav², Rahsan Cakmak², Haluk Ozener³, Fakhraddin Kadirov⁴, Ibrahim Guliev⁴, Ruben Stepanyan⁵, Merab Nadariya⁶, Galaktion Hahubia⁶, Salah Mahmoud⁷, K. Sakr⁷, Abdullah ArRajehi⁸, Demetris Paradissis⁹, A. Al-Aydrus¹⁰, Mikhail Prilepin¹¹, Tamara Guseva¹¹, Emre Evren^{12,18}, Andriy Dmi-trotsa¹³, S. V. Filikov¹³, Francisco Gomez¹⁴, Riad Al-Ghazzi¹⁵, 2006. Gebran Karam1-GPS constraints on continental deformation in the Africa–Arabia–Eurasia continental collision zone and implications for the dynamics of plate interaction. *J. Geophys. Res. Solid Earth* (1978–2012) 111(B5).
- Outkin, V.I., 2002. About movement inheritance of the Eurasian continent. In: *Proceedings of the International Seminar APSG 2002-Irkutsk*, M.GEOS, pp. 15–20.
- Gatinsky Yu, G., Rundquist, D.V., 2004. *Geodynamics of Eurasia: plate tectonics and blocks tectonics*. *Geotectonics* 38 (1), 3–20.
- Issawi, B., 1968. *The geology of Kurkur-Dungul area, Southwestern Desert, Egypt*. *Ann. Geol. Surv. Egypt* 102.
- (WCC) Woodward Clyde Consultants, 1985. Identification of earthquake sources and estimation of magnitudes and recurrence intervals. Internal Report, High and Aswan Dams Authority, Aswan, Egypt, pp. 135.

- Kebeasy, R.M., Maamoun, M.M., Ibraheim, E.M., 1982. Aswan Lake induced earthquakes. *Bull. Int. Instit. Seismol. Earthquake Eng. Jap.* 19, 155–160.
- Dach, R., Hugentobler, U., Fridez, P., Meindl, M. (Eds.), *Bernese GPS Software Version 5.0*, Astronomical Institute, University of Bern, 2007.
- McClusky, S., Balassanian, S., Barka, A., Demir, C., Ergintav, S., Georgiev, I., Gurkan, O., Hamburger, M., Hurst, K., Kahle, H., Kastens, K., Kekelidze, G., King, R., Kotzev, V., Lenk, O., Mahmoud, S., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R., Sanli, I., Seeger, H., Tealeb, Toksöz, M.N., Veis, G., 2000. Global positioning system constraints on plate kinematics and dynamics in the eastern mediterranean and caucasus. *J. Geophys. Res.* 105. <http://dx.doi.org/10.1029/1999JB900351>, issn: 0148-0227.
- McClusky, S., Reilinger, R., Mahmoud, S., Ben Sari, D., Tealeb, A., 2003. GPS constraints on Africa (Nubia) and Arabia plate motions. *Geophys. J. Int.* 155 (1), 126–138.
- Rothacher, M., Neilan, R., Plag, H.-P. 2008. The Global Geodetic Observing System (GGOS). Presented at the “AOGS – 2008” 5-th Annual Meeting, Busan, South Korea.