MODERN MOVEMENTS AND DEFORMATION OF THE EARTH'S CRUST OF AZERBAIJAN ACCORDING TO DATA OF GPS STATIONS

I.E. Kazimov[1], *A.F. Kazimova*[1]

INTRODUCTION

The Global Positioning System (GPS) has provided a new opportunity for direct observation of modern movements and deformations of the Earth's crust, as well as seismic-ionospheric disturbances. GPS studies helped quantify regional deformation in the plate interaction zone [12, 13, 15, 16, 18, 20, 21 and 24]. Regional studies of plate movement use fault orientation, local observations, and restrictions on the relative movement of plates.

The Eastern Mediterranean and the Caucasus are located among Eurasian, African and Arabian plates with complex tectonic activity, for example, volcanic eruptions, mountain building and a significant part of all earthquakes (Fig.1) [17].

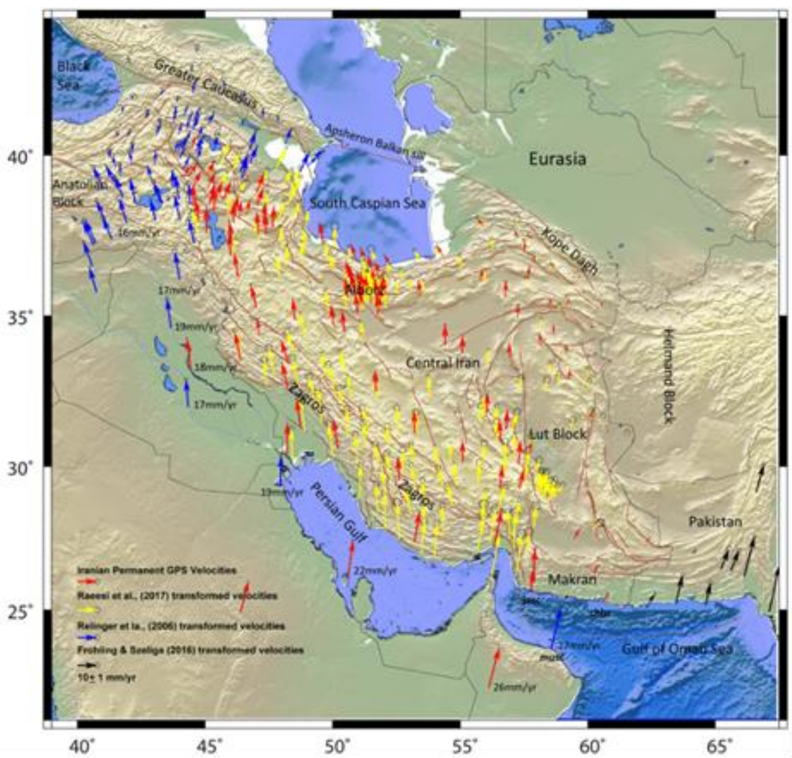

Figure 1. Map of the distribution of vectors of horizontal movements of the Mediterranean and the Caucasus [12] (Unified GPS velocity field relative to the Eurasia fixed frame. Reilinger et al. (2006; blue arrows), Frohling&Szeliga (2016; black arrows) and Raeesi et al. (2017; yellow arrows) velocity fields were transformed into the reference frame of IPGN (red arrows). Major faults of Iran, East Turkey and Caucasus are adapted from Hessami et al. (2003), Ghods et al. (2015) and Talebian et al. (2013)).

The East Anatolian Fault, the Caucasus, and the Zagros Mountains are active continental collision zones due to modern tectonic conditions and structures. The Eastern Mediterranean is one of the important regions for understanding fundamental tectonic processes, such as continental rift genesis, passive margin, subduction and accretion, collision and post collision [11]. These general processes are, in principle, investigated for large areas of the continental lithosphere in order to predict

[1] Republican Seismic Survey Center of Azerbaijan National Academy of Sciences

whether the region is seismic and not deformed at present. The tectonic perception of plates gives a description of continental deformation. The eastern Mediterranean focuses on connecting the Arabian, Eurasian, and Anatolian plates west of the convergence zone. The collision of Saudi Arabia with Eurasia is reduced in the zone of the lithosphere within the deforming region [2, 8].

According to these reconstructions, the Arabian plate advanced 200-600 km from its original place to the place where the continental Eurasian lithosphere was previously located.

As you know, Azerbaijan is part of the Alpine-Himalayan mountain belt formed in the Cenozoic on the southern edge of the East European platform as a result of a collision between the Eurasian and Arabian plates and survived a rapid rise over the past five million years. This work is devoted to the study of the strain rate of the Earth's crust in the territory of Azerbaijan according to GPS observations and its relationship with seismicity. [12, 13]

Tectonics of the studied region

The ongoing “invasion” of the Arabian Plate into Eurasia leads to a reduction in the lithosphere along the Main Caucasian Thrust (MCT), extending in the direction of SW-NE [2, 7, 17]. These regional tectonic processes, being the cause of the deformation of the Earth's crust, cause earthquakes that are historically recorded throughout the Caucasus.

As mentioned above, the territory of Azerbaijan is located in the zone of active collision of two plates, African and Eurasian. Reconstruction of plate tectonics indicates that the collision of the Arabian plate with the Eurasian plate lasts 10-30 million years, right up to the present stage. The speed of movement of the Arabian Plate to the north relative to Eurasia since the beginning of their collision is more or less constant and equal to approximately 20 mm/year [6, 9, 10, 16, 17].

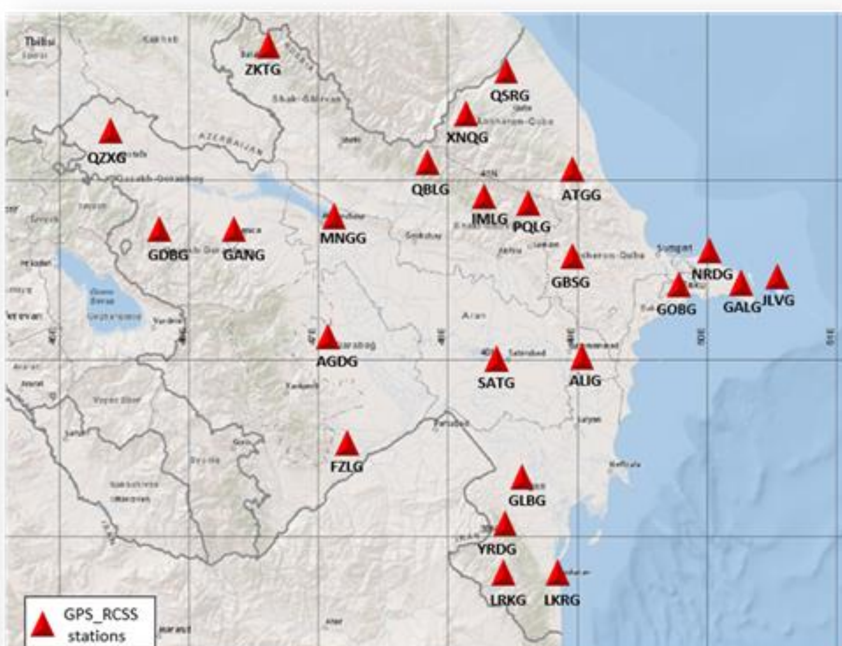

Figure 2. Network of GPS stations in Azerbaijan

Iran’s modern tectonics is the result of convergence between north and south among relatively undeformed territories in the southwest (Arabia) and northeast (Eurasia). The NUVEL-1 A global plate motion model predicts a convergence rate of 3–3.5 cm/year. The deformation of Iran includes intracontinental shortening, with the exception of its southeastern margin (Makran), where the oceanic lithosphere of Oman is subducted northward under southeastern Iran (Fig. 1). Within Iran, most of the deformation probably occurs in the main zones (Zagros, Alborz, Kopetdag) and along large faults that surround the blocks (Central Iranian desert, Loot block and the southern Caspian Sea) with moderate relief and seismicity [17]. The exact distribution of deformation between these tectonic structures is unclear.

Central Iran, Zagros and Makran - this segment of the Alpine-Himalayan belt, lying to the east of the northern ledge of the Arabian Plate.

The Zagros zone, which corresponds to a ridge with a length of up to 1300, a width of 250 and a height of 4.5 km, is formed by a powerful, up to 8-10 km, complex of Paleozoic, Mesozoic and Cenozoic sediments of the passive margin of the Arabian Plate, crushed into large and very long (up to 350 km) folds that gradually change the strike from northwest to east northeast [12].

GPS stations data analysis

At present, 24 GPS stations function in Azerbaijan. The network was created in 2012 (Fig. 2). The network geometry and the location of the measurement points were determined based on the neotectonic structure of the region to characterize as much as possible the relative displacements of the individual elements of this structure and the general deformation of the Earth’s crust [3, 4].

GPS data analysis was performed using the GAMIT (version 10.05; Kingand Bock 2001) and GLOBK (version 10.0; Herring 2001) software in the three-step approach described by Feigletal. (1993) [20, 21]. The basis for the velocity estimation is an analysis of the time series of GPS station coordinates calculated from the primary data, which are sets of phase and code measurements at two frequencies lasting 24 hours with a recording interval of 15 s. To assess the speeds of the stations being determined, it is necessary that the network has at least one reference point, and preferably several. We included in this analysis 11 nearby IGS network reference stations: ARTU (Artie, Russia), CRAQ (Simeiz, Ukraine), TEHN (Tehran, Iran) POLV (Poltava, Ukraine), MDVJ (Mendeleyevo, Russia) ANKR (Ankara, Turkey) NICO (Nicosia, Cyprus) DRAG) POL2 (Bishkek, Kyrgyzstan) YIBL (Yibal, Oman) BZGN (Bazergan, Iran) [5] with positions and speeds in ITRF2000 as connecting links with the global reference system (Table 1).

We used the Earth rotation parameters IERS (International Earth Rotation Service) and applied the antenna phase center models depending on azimuth and elevation, following the tables recommended by IGS. Figure 3 shows a map of the distribution of vectors of horizontal movements for 2019. The arrows in the Figure show the direction of the velocity vectors, and the values of the velocities are characterized by the length of the arrows according to the scale shown in the lower right corner of the map. In addition, in Fig.4 shows the temporal variations in the amplitude fluctuations of GPS stations for 2019.

In addition, a speed map of horizontal movements of the geodetic network of GPS stations of Azerbaijan for 2019 was built (Fig. 5). As an analysis of the distribution of speeds shows, the average values of the speeds of horizontal displacements of points to the north and east are not constant, and the processes of shortening the surface of the Earth's crust are also not constant in the study region.

The error in determining the speed varies mainly in the limit of less than 0.6 mm/year, which allows a fairly accurate estimate of the convergence of plates across the Caucasus mountain system (i.e., the error is 5% of the total convergence rate). As one of the main sources of GPS positioning errors, ionospheric delays play a very important role in data processing. Since it is difficult to accurately model the attenuation of the ionosphere, to prevent the effects of ionospheric delays, almost all GPS data processing programs always use a linear combination without ionosphere (LC), including GAMIT, Bernese, GIPSY and PANDA.

The high-speed field of GPS observations quite clearly reflects the movement of the north-north-east (NNE) direction in Azerbaijan and in the adjacent regions of the Lesser Caucasus relative to Eurasia.

Table 1. Parameters of the world reference stations of the IGS network: (ARTU, CRAQ, TEHN, POLV, MDVJ, ANKR, NICO, DRAG, POL2, YIBL, BZGN).

IGS_GPS	region	country	Long,°	Lat,°	reciver	antenna	satellite
ANKR	Ankara	Turkey	39,88	32,75	LEICAGR 30	LEIAR10 + NONE	GPS GLONASS Galileo BeiDou SBAS
ARTU	Artie	Russia	56,43	58,56	ASHTECH Z-XII3	ASH700936D_M + DOME	GPS
CRAO	Simeiz	Ukraine	44,41	33,99	ASHTECH UZ-12	ASH701945C_M + SCIS	GPS
DRAG	Mezoke	Israel	31,59	35,39	JAVAD TRE_3 DELTA	ASH700936D_M + SNOW	GPS GLONASS
MDVJ	Mendele yevo	Russia	56.02	37.21	TPS NETG3	JPSREGANT_DD_E1 + NONE	GPS GLONASS
NICO	Nicosia	Cyprus	35,14	33,4	LEICA GR25	LEIAR25.R4 + LEIT	GPS GLONASS Galileo BeiDou SBAS
POL2	Bishkek	Kyrgyzstan	42,68	74,69	ASHTECH UZ-12	TPSCR.G3 + NONE	GPS
POLV	Poltava	Ukraine	49,6	34,54	LEICA GR10	LEIAR10 + NONE	GPS GLONASS Galileo
TEHN	Tehran	Iran	35,7	51,33	TRIMBLE NETR9	TRM57971.00 + NONE	GPS GLONASS
YIBL	Yibal	Oman	22,18	56,11	TRIMBLE NETR9	ASH701945C_M + NONE	GPS

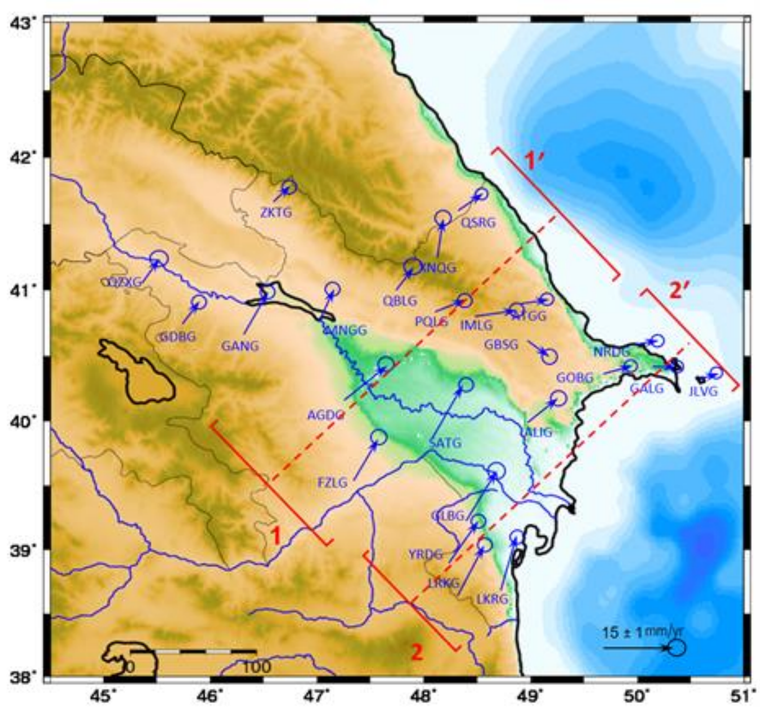

Figure 3. Map of the distribution of vectors of horizontal movements for 2019

The arrows in the Figure show the direction of the velocity vectors, and the velocity values are characterized by the length of the arrows according to the scale shown in the lower right corner of the map.

Arrows represent the horizontal station velocities in mm/year referred to the ITRF2008 reference frame. Error ellipses were calculated to the 95% confidence interval.

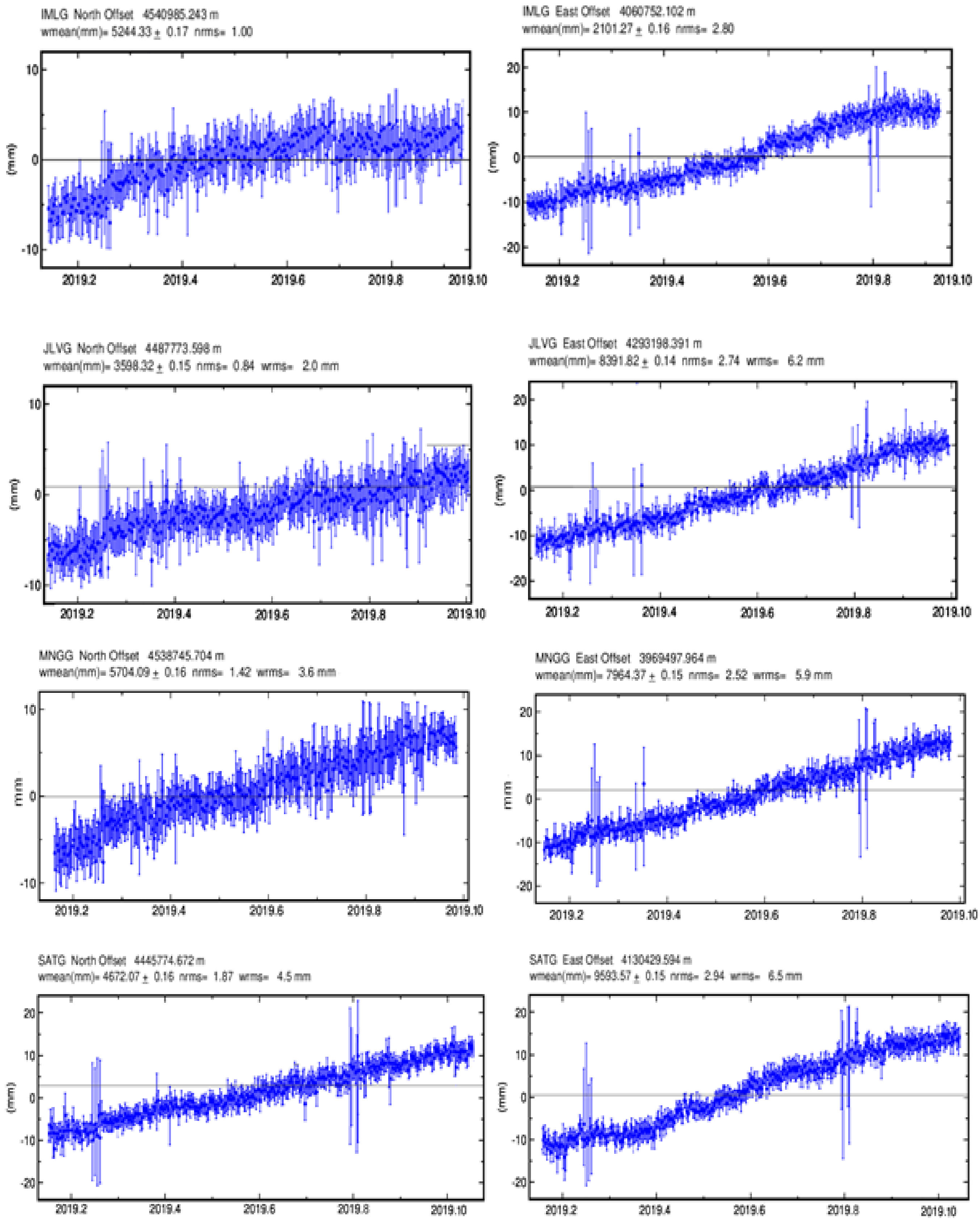

Figure 4. Temporal variations in the amplitude fluctuations of GPS RSSC (IML, JLV, SAT, MNG) stations for 2019.

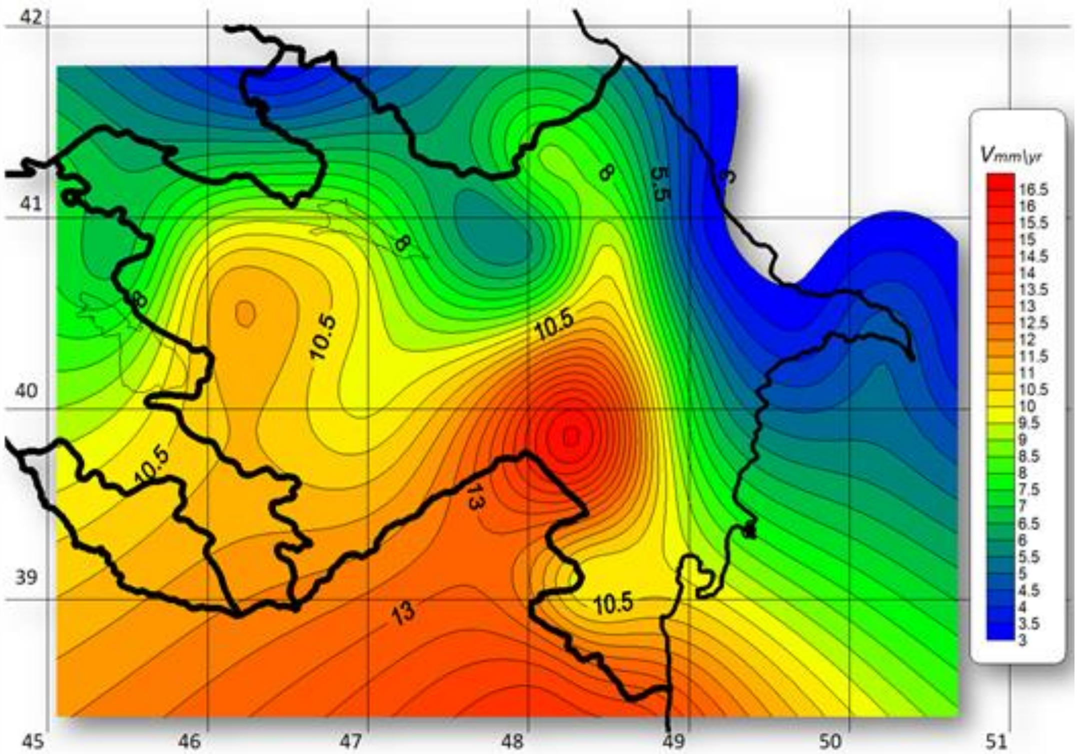

Figure 5. Speed of horizontal movements according to the network of GPS stations of Azerbaijan for 2019.

Table. 2. Coordinates and speeds of horizontal displacements of GPS stations of the territories of Azerbaijan according to profile 1-1

N	coordinates		V*Evel(mm/yr)*	V*Nvel.(mm/yr)*	AZM , °	V *vel(mm/yr)*	GPS RSSC *stations*
	Long,°	Lat,°					
1	48.94	40.54	5.24	-3.88	127	6.5	GBSG
2	48.94	40.86	5.02	0.63	83	5.1	ATGG
3	48.59	40.79	9.26	2.34	76	9.6	PQLG
4	48.39	39.94	7.91	14.52	29	16.5	SATG
5	48.26	41.52	5.32	4.63	49	7.1	QSRG
6	48.18	40.79	5.85	2.62	66	6.4	IMLG
7	48.14	41.17	0.42	8.36	10	8.4	XNQG
8	47.84	40.95	2.96	4.81	32	5.6	QBLG
9	47.32	39.46	5.92	10.5	29	12.1	FZLG
10	47.11	40.11	6.13	7.69	47	9.8	AGDG

The discussion of the results

The GPS observation speed field clearly illustrates the movement of the Earth's crust in the north-west direction in Azerbaijan and related regions of the Lesser Caucasus relative to Eurasia. The most explicit feature of the velocity field is the decrease in speed at the observation points located perpendicular to the Main Caucasian Thrust (MCT) (i.e., at the stations PQLG, XNGG, ZKTG, ATGG, IMLG and GBLG). GPS observation points located along the MCT show a decrease in speed in a westerly direction. N-NE motion of the Earth's surface is interpreted as one of the reasons for the accumulation of stresses on this thrust. In addition, there is a tendency of horizontal movement within the Kura Depression and the Lesser Caucasus, where the speed increases from west to east along the strike of the mountain range.

In order to clarify the nature of GPS velocities in the seismic zones of the Kura Depression, profiles 1-1’ and 2-2 were constructed in the strike cross of the Greater and Lesser Caucasus, as well as in the direction from the Talysh region to the Absheron Peninsula (Fig. 6-7). Table (2-3) presents the coordinates and speeds of the horizontal displacements of GPS stations in Azerbaijan.

Table. 3. Coordinates and speeds of horizontal displacements of GPS stations of the territories of Azerbaijan according to profile 2-2

N	coordinates		V*E* *vel(mm/yr)*	V*N* *vel.(mm/yr)*	AZM , °	V *vel(mm/yr)*	GPS *stations*
	Long,°	Lat,°					
1	50.58	40.31	3.43	1.2	81	3.6	JLVG
2	50.16	40.41	4.8	-0.4	95	4.8	GALG
3	49.99	40.58	3.77	1.13	73	3.9	NRDG
4	49.73	40.40	3.55	0.85	77	3.7	GOBG
5	49.01	39.96	6.09	5.55	48	8.2	ALIG
6	48.78	38.71	4.15	13.23	17	13.9	LKRG
7	48.39	39.24	-1.97	5.01	21	10.2	GLBG
8	48.34	38.64	6.16	13.36	25	14.7	LRKG
9	48.24	38.91	7.18	11.49	32	13.5	YRDG

On the 1-1 'profile in the strike cross of the Greater and Lesser Caucasus, there is a noticeable decrease in the speeds of horizontal movements at an epicentral distance of 50 km (Fig. 6), which indicates the approach of the Lesser Caucasus to the Kura Depression at a speed of 12-16 mm/year and a gradual shift of Kura Depression under the Greater Caucasus.

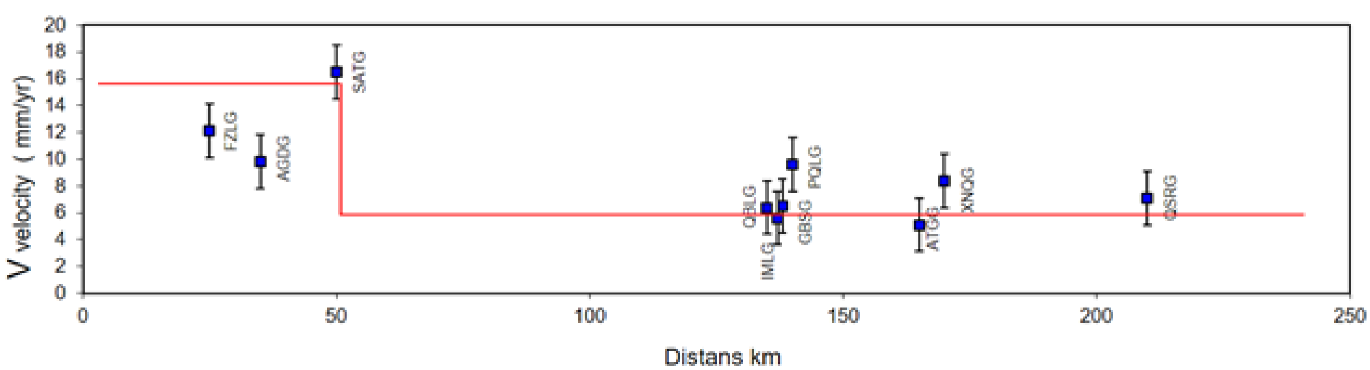

Figure 6. Components of the speeds of horizontal movements of GPS observation points along profile 1-1

In Figure, the profile is shown in the direction from the Talysh region to the Absheron peninsula (SW-NE direction). The speeds of the stations Nardaran, Gobu, Gala and Zhiloy Island, which are included in the Absheron zone, are characterized by almost similar displacement rates (5.3 mm/year, 4.7 mm/year, 4.5 mm/year, and 4.4 mm/year, respectively). The profile shows a noticeable decrease in the northern component of the displacement rates compared to the high values of points located in the southwestern part of the selected profile (LKRG_GPS=13.4 mm/year, GLBG_GPS=13.4 mm/year, YRDG_GPS=12.0 mm/year). In addition, there is a noticeable increase in the azimuthal angles of the Absheron stations indicating a clockwise movement in the east-south-east direction to 130º.

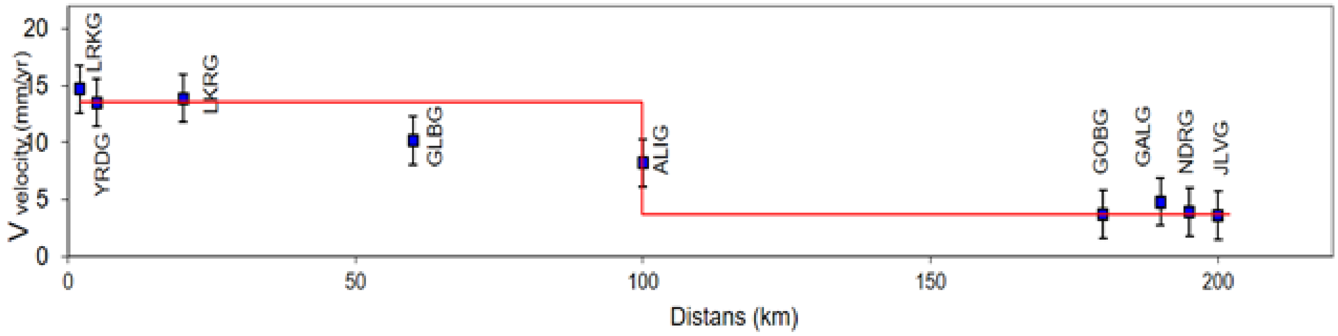

Figure 7. Components of the speeds of horizontal movements of GPS observation points along profile 2-2

At points located in the Lesser Caucasus and the Kura Depression within eastern Azerbaijan, a GPS station located in the coastal zone of the Caspian Sea slightly south of the Absheron Peninsula; there is a sharp decrease in speeds in points and rotation of velocity vectors in the clockwise direction. A sharp decrease in the velocity and rotation of the vectors occurs east of the longitude 40°E along the West Caspian Fault and on the West Caspian Fault a right-side shear movement occurs at a speed of 14±1 mm/year. The existing distribution of velocities and their gradients causes various values of stress accumulation along the MCT, which may affect the seismic mode of the study area.

Conclusion

Detected increase in speed in 2019 at Lerik, Lankaran, Jalilabad, Agdam and Saatli stations, it is the most significant feature of the velocity field in the region where the crust decreases across the eastern MCT segment (longitude 48º). In western Azerbaijan, a reduction in the size of the Earth's crust in the Greater Caucasus occurs between the MCT and the southern wing of the North Caucasian Thrust (NCT).

It was established that along the Kura Depression in the direction from the Middle Kura Depression to the Lower Kura Depression (i.e., from northwest to southeast), a gradual increase in the speeds of horizontal movements from 7.3 to 15.5 mm/year is observed, which is characterized by the compression condition. Note that over the past year, the zone of the Lower Kura Depression is characterized by the manifestation of high seismic activity, expressed in several earthquakes with magnitudes greater than 5, characterized by a reverse fault type.

In addition, a noticeable decrease in horizontal movement speeds at an epicentral distance of 65 km is observed in the strike cross of the Greater and Lesser Caucasus, which indicates the thrust of the Lesser Caucasus on the Kura Depression with an average speed of 10-12 mm/year and the gradual shift of the Kura Depression beneath the Greater Caucasus. On average, in the territory of the Greater Caucasus, at different stations, it was 3.1–9.6 mm/year, and in the Lesser Caucasus, 7–10.1 mm/year.

At GPS stations Nardaran, Gobu, Gala and Zhiloy Island, which are part of the Absheron zone, almost similar values of horizontal displacement velocities are observed (3.9 mm/year, 3.7 mm/year, 4.8 mm/year, and 3.6 mm/year, respectively). In the direction from the Talysh region to the Absheron peninsula (SW-NE direction), a noticeable decrease in the northern component of the displacement rates is observed compared to the high values of the points located in the southwestern part of the selected profile Lerik, Lankaran, Yardimly (14.7 mm/year, 13,9 mm/year, 13.5 mm/year). In addition, there is a noticeable increase in the azimuthal angles of the Absheron stations, indicating a clockwise movement in the east-south-east direction from 40 ° to 80° -120°.

Thus, based on the data obtained for 2019, the average strain rate in the north-north-east of Azerbaijan is 8.4 mm per year.

REFERENCES

1. Етирмишли Г.Дж., Рзаев А.Г., Казымов И.Э., Казымова С.Э. Моделирование геодинамической ситуации Куринской впадины на основе новейших сейсмологических, геодезических и магнитометрических данных, Бюллетень Оренбургского научного центра УрЩ РАН, 2018, №2, с. 1-11

2. Кадиров Ф.А., Мамедов С.К., Сафаров Р.Т., Исследование современной геодинамической ситуации и опасности землетрясений деформации земной коры территории Азербайджана по 5-летним GPS-данным, Современные методы обработки и интерпретации сейсмологических данных, Обнинск, 2015 г., с. 156-162

3. Казымов И.Э. Геодинамика Абшеронского полуострова, Современные методы обработки и интерпретации сейсмологических данных, Обнинск, 2015 г., с. 163-166

4. Казымов И.Э., Казымова А.Ф. Современная геодинамика Азербайджана по данным GPS станций за 2017-2018 гг., SEISMOPROGNOSIS OBSERVATIONSIN THE TERRITORY OF AZERBAIJAN, Volume 16, № 1, 2019, с 35-42

5. Казымов И.Э., Рахимли З.С., Юзбашиева С.С. Общие принципы обработки спутниковых измерений сети GPS станций Азербайджана, Геофизический институт Владикавказского научного центра РАН Геология и Геофизика Юга России, №1/2017, Владикавказ 2017, ISSN 2221-3198, с 100-114

6. Robert E. Reilinger, Simon McClusky, Philippe Vernant, Shawn A. et.al.GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions: EASTERN MEDITERRANEAN ACTIVE TECTONICS, journal of geophysical research vol. 111, 2006, DOI: 10.1029/2005jb004051

7. Yetirmishli G.J., Veliyev H.O., Kazimov I.E., Kazimova S.E. Correlation between GPS observation outcomes and depth structure in studying horizontal movements, Бюллетень Оренбургского научного центра УрЩ РАН, 2018, №4, p. 72-85

8. Aktug B., Meherremov, E., Kurt M., Özdemir S., Esedov N., Lenk O., 2013a. GPS constraints on the deformation of Azerbaijan and surrounding regions. J. Geodyn. 67, 40–45.

9. Aktug B., Nocquet J.M., Cingöz A., Parsons B., Erkan Y., England P., Lenk O., Gürdal M.A., Kilicoglu A., Akdeniz H., Tekgül A., 2009. Deformation of western Turkey from a combination of permanent and campaign GPS data: limits to block-like behavior. J. Geophys. Res. Solid Earth 114, B10404.

10. Aktug B., Parmaksız E., Kurt M., Lenk O., Kılıçoglu A., Gürdal M.A., Özdemir S., 2013b. Deformation of Central Anatolia: GPS implications. J. Geodyn. 67, 78–96.

11. Robertson A., Mountrakis D., 2006. Tectonic Development of the Eastern Mediterranean Region. Geol. Soci. London Spec. Publ. 260, 1–9. Shen, Z.-K., Jackson, D.D., Ge, B.X., 1996.

12. Mahmoud S., Reilinger R., McClusky S., Vernant P., Tealeb A., 2005. GPS evidence for northward motion of the Sinai Block: implications for E. Mediterranean tectonics. Earth Planet. Sci. Lett. 238, 217–224.

13. Mahmoud Y., Masson F., Meghraoui M., Cakir Z., Alchalbi A., Yavasoglu H., Yonlu O., Daoud M., Ergintav S., Inan S., 2013. Kinematic study at the junction of the East Anatolian fault and the Dead Sea fault from GPS measurements. J. Geodyn. 67, 30–39.

14. Masson F., Anvari M., Djamour Y., Walpersdorf A., Tavakoli F., Daignières M., Nankali, H., Van Gorp, S., 2007. Large-scale velocity field and strain tensor in Iran inferred from GPS measurements: new insight for the present-day deformation pattern within NE Iran. Geophys. J. Int. 170, 436–440.

15. McClusky S., Balassanian S., Barka A., et al., 2000. Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus. J. Geophys. Res. Solid Earth 105, 5695–5719.

16. 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, 126–138. McKenzie D., 1972. Active tectonics of the Mediterranean region.Geophys. J. Int. 30, 109–185.

17. McKenzie D., 1978. Active tectonics of the Alpine—Himalayan belt: the Aegean Sea and surrounding regions. Geophys. J. Int. 55, 217–254. McKenzie, D.P., 1970. Plate tectonics of the Mediterranean region. Nature 226, 239– 243.

18. Nyst M., Thatcher, W., 2004. New constraints on the active tectonic deformation of the Aegean. J. Geophys. Res. Solid Earth 109, B11406. http://dx.doi.org/10.1029/ 2003JB002830.

19. Regard V., Bellier O., Thomas J.C., Abbassi M.R., Mercier J., Shabanian E., Feghhi K., Soleymani S., 2004. Accommodation of Arabia-Eurasia convergence in the Zagros-Makran transfer zone, SE Iran: a transition between collision and subduction through a young deforming system. Tectonics 23. TC4007.

20. Reilinger R., McClusky S., Vernant P., et al., 2006. GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions. J. Geophys. Res. Solid Earth 111, B05411

21. Reilinger, R.E., McClusky, S.C., Oral, M.B., King, R.W., Toksoz, M.N., Barka, A.A., Kinik I., Lenk O., Sanli I., 1997. Global Positioning System measurements of presentday crustal movements in the Arabia-Africa-Eurasia plate collision zone. J. Geophys. Res. Solid Earth 102, 9983–9999.

22. Jackson J., McKenzie D., 1984. Active tectonics of the Alpine—Himalayan Belt between western Turkey and Pakistan. Geophys. J. Roy. Astron. Soc. 77, 185– 264.

23. Jackson J., Priestley K., Allen M., Berberian M., 2002. Active tectonics of the South Caspian Basin. Geophys. J. Int. 148, 214–245. Jin, S.G., Park, P.-H., 2006. Strain accumulation in South Korea inferred from GPS measurements. Earth Planets Space 58, 529–534.

24. Jin S.G., Park P.-H., Zhu W., 2007b. Micro-plate tectonics and kinematics in Northeast Asia inferred from a dense set of GPS observations. Earth Planet. Sci. Lett. 257, 486–496.