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Original paper

Geodynamics of the territory of Azerbaijan on the basis of GPS data in 2017-2019 yy.

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Abstract: **Relevance.** the results obtained, in conjunction with these seismicity and the mechanisms of earthquakes, allow to determine the modern geodynamic situation of the studied region. **The aim** of the work was geodetic analysis and comparison of the results of GPS stations obtained for the period 2017-2019. on the territory of Azerbaijan. **Methods.** In the process of studying geodynamic processes using GPS technologies, two spatio-temporal modes are mainly used: a single redefinition of the initial coordinates of the points of geodetic networks and the displacement of the initial values of deformations. GPS data were processed using the GAMIT/ GLOBK program. **Results.** One of the most pronounced features of the GPS velocity field is a decrease in the velocities of GPS stations (northern component of VN), perpendicular to the direction of expansion of the Greater Caucasus surface from south to north. The movement of the earth's surface to the north-north-east is interpreted as one of the reasons for this accumulation of stress. In addition, there is a tendency for horizontal movement in the Kura Depression and the Lesser Caucasus, which is reflected in the increase in velosity from west to east along the extension of the mountain range. It was determined that the earth's crust shortened at a velosity of ~ 5 mm / year in the Baku (Absheron peninsula). During 2019, on average, up to 8.4 mm per year in the north-northeast direction is observed for the territory of Azerbaijan. Separate velocities were also calculated for each station. Compared to 2018, it was determined that out of 24 GPS stations PQLG, XNQG, IMLG, QZXG, GANG, MNGG, FZLG, SATG, LKRG, LRKG and YRDG stations, the value of horizontal velocities increased by 0.5-7.0 mm/ year, ZKTG, QBLG. At QSRG, ATGG, GDBG, AGDG, ALIG, JLVGG, GALG, GOBG and NDRG stations, the velocities values decreased by 0.5-3.1 mm/year. In 2019, the highest velocities were observed at Ganja, Mingachevir and Saatli stations. On average, velocities were 3.1-9.6 mm/year in the Greater Caucasus, 6.9-16.5 mm/year in the Kura Basin, 10.2-14.8 mm/year in the Talish area and on the Apsheron Peninsula. It varies between 3.6-4.8 mm/ year.

Keywords: geodynamic model, GPS stations, collision zone in the Greater Caucasus, Zagros mountain.

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ГЕОТЕКТОНИКА И ГЕОДИНАМИКА

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Оригинальная статья

Геодинамика территории Азербайджана на основе данных GPS за 2017-2019 гг.

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Резюме: Актуальность работы: полученные результаты в совокупности с приведенной сейсмичностью и механизмами землетрясений позволяют определить современную геодинамическую ситуацию изучаемого региона. **Целью работы** являлся геодезический анализ и сравнение результатов GPS-станций, полученных за период 2017-2019 гг. на территории Азербайджана. **Методы работы.** В процессе изучения геодинамических процессов с использованием GPS технологий в основном применяются два пространственно-временных режима: однократное переопределение начальных координат точек геодезических сетей и смещение начальных значений деформаций. Данные GPS обрабатывали с помощью программы GAMIT/GLOBK. **Результаты работы.** Одной из наиболее ярко выраженных особенностей поля скорости GPS является уменьшение скоростей станций GPS (северный компонент VN), перпендикулярных направлению расширения поверхности Большого Кавказа с юга на север. Движение земной поверхности на север-северо-восток интерпретируется как одна из причин такого накопления напряжения. Кроме того, существует тенденция горизонтального движения в Курской впадине и на Малом Кавказе, что отражается в увеличении скорости с запада на восток по продолжению горного хребта. Было установлено, что земная кора сокращалась со скоростью ~ 5 мм/год в Баку (Апшеронский полуостров). В течение 2019 года в среднем по территории Азербайджана наблюдается до 8,4 мм в год в северо-северо-восточном направлении. Отдельные скорости были также рассчитаны для каждой станции. По сравнению с 2018 годом было определено, что из 24 GPS станций PQLG, XNQG, IMLG, QZXG, GANG, MNGG, FZLG, SATG, LKRG, LRKG и YRDG, значение горизонтальных скоростей увеличилось на 0,5-7,0 мм/год, ZKTG, QBLG. На станциях QSRG, ATGG, GDBG, AGDG, ALIG, JLVGG, GALG, GOBG и NDRG значения скоростей снизились на 0,5-3,1 мм/год. В 2019 году самые высокие скорости наблюдались на станциях Гянджа, Мингячевир и Саатлы. В среднем скорости составляли 3,1-9,6 мм/год на Большом Кавказе, 6,9-16,5 мм/год в бассейне Куры, 10,2-14,8 мм/год в Талышском районе и на Апшеронском полуострове. Колебания находятся в пределах 3,6-4,8 мм/год.

Ключевые слова: геодинамическая модель, GPS-станции, зона коллизии на Большом Кавказе, гора Загрос.

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Introduction

The most important element in creating a geodynamic model is to take into account the changes that occur under the influence of modern movements of the Earth's crust on the Earth's surface. They often determine the activity of many destructive natural phenomena and affect the course of exogenous, as well as processes that occur as a result of human economic activity. The prediction of unfavorable geodynamic processes requires not only knowledge of the occurrence of the processes themselves, concentrated in adequate models, but also, of course, the initial state of the rock massifs, based on the collection of experimental data [Robertson, Mountrakis, 1996; Tapponnier et al., 2001; Milyukov et al., 2015; Pevnev, 2020, 2021].

One of the most widespread methods in the world today is the method based on global navigation satellite system (GNPS) technology. With the advent of GPS technologies, the first of the implemented QNPS technologies, it became possible to carry out high-precision (3-10 mm in all sizes) geodetic monitoring in relatively large areas of the site with relatively little money and time.

Modern movements on the Earth's surface reflect tectonic processes within the Earth's crust. However, the accuracy of determining the vertical velocity component through GPS observations is many times less than the accuracy of determining the horizontal velocity organizers. The deformation of the earth's crust can be considered continuous (continuous) and can be considered as a change in the shape and volume of an object. Thus, it is possible to determine the strain tensor at any given point on the earth's crust and on its surface for a given time [Jackson, McKenzie, 1984].

For the first time in the territory of Azerbaijan, the GPS tracking system was established in 1998 jointly with the Institute of Geology and Geophysics of ANAS and the Massachusetts Institute of Technology. Thus, the basis for the study of modern geodynamics of the territory of Azerbaijan on the basis of GPS technology was laid.

The velocity range obtained from GPS observations over the last 20 years clearly describes the movement of the earth's crust in the north-northeast direction at a velocity of 18-25 mm/year relative to Eurasia in the territories adjacent to Azerbaijan and the Lesser Caucasus. The African plate is moving north at a velocity of 10 mm/year and affects the geodynamics of the Zagros mountain structure [Aktug, 2013, Masson, 2007].

The purpose of our study was to calculate the modern rates of horizontal displacement of individual tectonic blocks within the country and to analyze the impact of strong earthquakes in 2017-2019.

Methods of studying of modern horizontal movements

In recent years, the Republican Seismological Survey Center (RSSC) uses the methods of satellite geodesy. The combination of traditional ground and satellite measurements allows you to successfully solve the assigned tasks. 24 GPS-receivers of the geodetic class of the company "Trimble" were used for the conduct of satellite geodetic measurements in the RSSC (Fig. 1) [Kazimov, Kazimova, 2019].

Almost all GPS stations (especially their U-components) present not only linear variations, but also significant non-linear variations in seasonal signals (defined as annual and semiannual variations), superimposed against approximately the strength of the band background. Linear variations can be well explained as the movement of the plate, while only a fraction of the nonlinear changes can be explained. In fact, nonlinear variations were mainly caused by unidentified internal errors associated with GPS technique and external unmodeled geophysical effects [Wright, 2004].

Moreover, it will become an obstacle to time series analysis and prevent the separation of unmodeled geophysical effects from nonlinear changes. As one of the main sources of GPS positioning errors, ionospheric delays play a very important role in data processing. Because it is difficult to accurately simulate ionospheric attenuation, virtually all GPS data processing programs always use a linear combination without an ionosphere (LC), including GAMIT, to avoid ionospheric delay effects [McClusky, 2000, 2003].

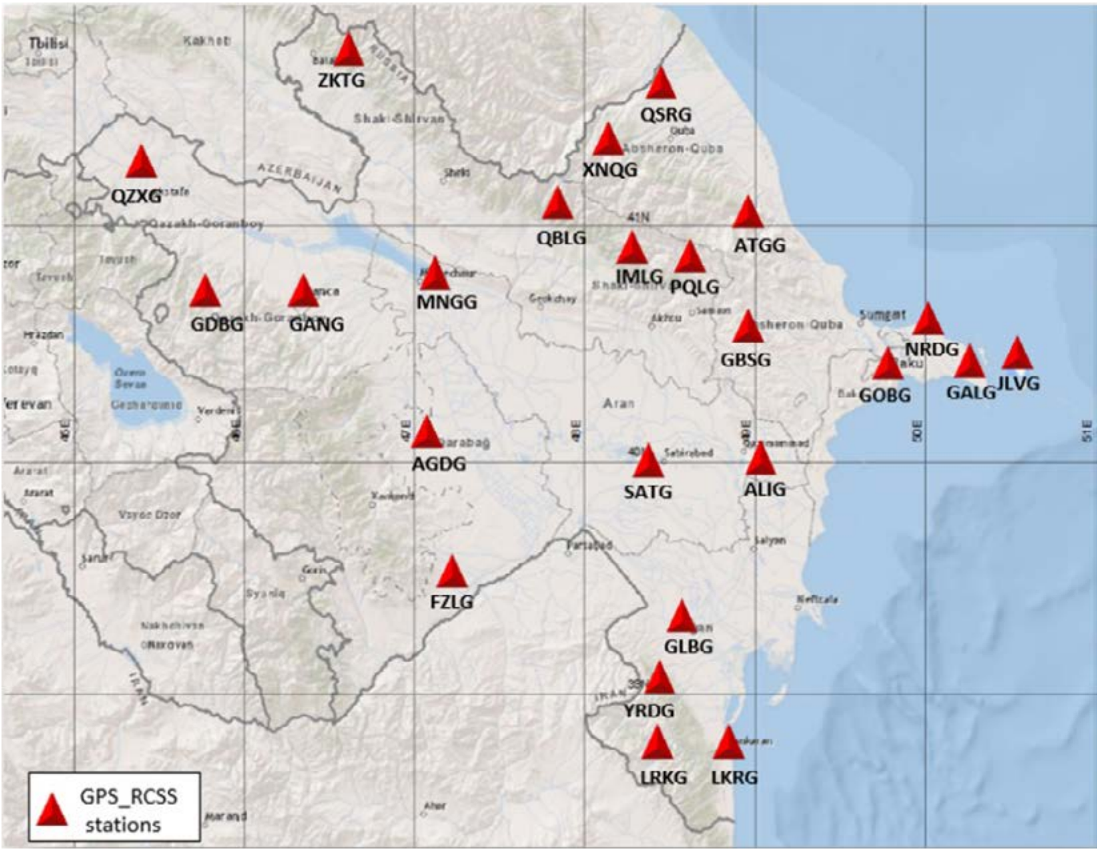

Fig. 1. RSSC's network of GPS stations /
Рис. 1. Сеть GPS-станций РЦСС

Thus, when studying geodynamic processes using GPS technologies, two spatio-temporal modes are mainly used: one-time redefinition of the initial coordinates of points of geodetic networks, and displacements of the reference values of deformations.

GPS data were processed using the GAMIT / GLOBK software [Herring, 2010; Kadirov, 2015] according to the procedure described in [Reilinger et al., 2006].

The refinements of the geodetic coordinates of the stations were processed on the server by the GPS processing service AUSPOS (version: AUSPOS 2.2)

The APSPOS Online GPS Processing Service uses International GNSS Products (IGS) (Finite, Fast, Ultrafast subject to availability) to compute accurate coordinates to ITRF anywhere on Earth and GDA94 in Australia. The service is designed to process only biphasic GPS phase data. When refining the coordinates of the GPS stations in this study, data from 14 closely spaced reference stations of the IGS network were added [Kazimov et al., 2017].

In addition, the parameters of the orbital-terrestrial orientation of all GPS stations and atmospheric zenith delays from the dual-frequency stations were calculated.

Processing of GPS data was carried out using the GAMIT / GLOBK (Kalman filter) 10.71 and TRACK software package, which form a complete set of programs for analyzing GPS measurements. The software was developed by Massachusetts Institute of Technology (MIT), Scripps Institute of Oceanography and Harvard University [Herring, 2003].

The data obtained as a result of experimental work on the current stress-strain state of the earth's crust and the patterns of its change in time, on the one hand, provide new fundamental knowledge about the nature of natural deformation processes occurring in the upper part of the earth's crust and the effect on the formation of the stress state [Conrad, Lithgow-Bertelloni, 2004; Thatcher, 2003].

Geodynamics of the territory of Azerbaijan in 2017-2019 on the basis of GPS data

Thus, in order to determine the velocities and directions of horizontal movements of individual tectonic blocks of the Earth's crust in the territory of Azerbaijan, the data obtained in 2017-2019 were analyzed. It was determined that 1.0-2 mm north-northwest movements are recorded in the Greater and Lesser Caucasus in 2017, and 1.5-2.5 mm northeast movements in the Middle and Lower Kura basin in 2017. Values for the GPS station located in the Deep Clock well increase to 3.5 mm. Hashchin The values of displacement at the station located on the island of Gilov in the Caspian Sea vary between 2-3 mm.

Based on the data obtained in 2017, on average, up to 10 mm of north-northeast movements are observed per year for the territory of Azerbaijan. Separate velocities were also calculated for each station. Compared to 2016, it was determined that out of 24 GPS stations, the values of horizontal velocities at QSRG, PQLG and ALIG stations increased by 1-2 mm/y. Velosity values have dropped at the remaining 21 stations. At stations located on the Absheron Peninsula, the velosity drops to 4-5 mm/y.

It was determined that QSRG, SATG, ALIG, LRKG and LRKG stations have the highest velocities in 2017. The map of epicenters for the last 10 months of 2017 shows that the most active regions are the Greater Caucasus, Saatli, Talish and the middle part of the Caspian Sea. The depth of each strong earthquake can indicate the depth of movement of any tectonic block. Thus, the epicenters of earthquakes in Zagatala, Sheki and Gabala regions in 2017 show the advantage of displacement movements in the direction of the left-lateral earthquake [Yetirmishli et al., 2017]. The depth of these earthquakes varies from 10 to 20 km. ZKTG, QZXG, GDBG and QBLG GPS stations located in this area show their values in the direction of 8.9 mm/y, 7.8 mm/y, 6.7 mm/y and 8.1 mm/y. At local time 07:24:19, 24 km from Saatli was registered the earthquake. It was felt in the epicenter with intensity about 5 points. The magnitude of the earthquake was 5.4 and the depth was 48 km. It can be considered that the earthquake was due to the movement of the block, which descended 48 km. Note that in 2017, the velosity values at the SATG GPS station reached 14.7 mm/y.

In 2018, it was determined that 1.0-2 mm north-northwest movements are recorded in the Greater and Lesser Caucasus in 2018, and 1.5-2.5 mm northeast in the Middle and Lower Kura basin. actions are recorded. At the GPS station located in the Deep Saatli well, the velosity of horizontal displacement during the year was determined to be 9.6 mm / year. Also, the values of displacement at the station located on the island of Gilov in the Caspian Sea were set at 5.7 mm. Based on the data obtained in 2018, up to 8 mm of north-northeast movements are observed in the territory of Azerbaijan on average per year. Separate velocities were also calculated for each station. Compared to 2017, it was determined that out of 24 GPS stations, JLVGG, GALG, GOBG and NDRG stations increased the values of horizontal velocities by 1-1.7 mm/y. Velosity values have dropped at the remaining 20 stations.

In order to reveal the relationship of horizontal movements with the geodynamic conditions of values, a comparison was made with a map of the epicenters of strong (ml>

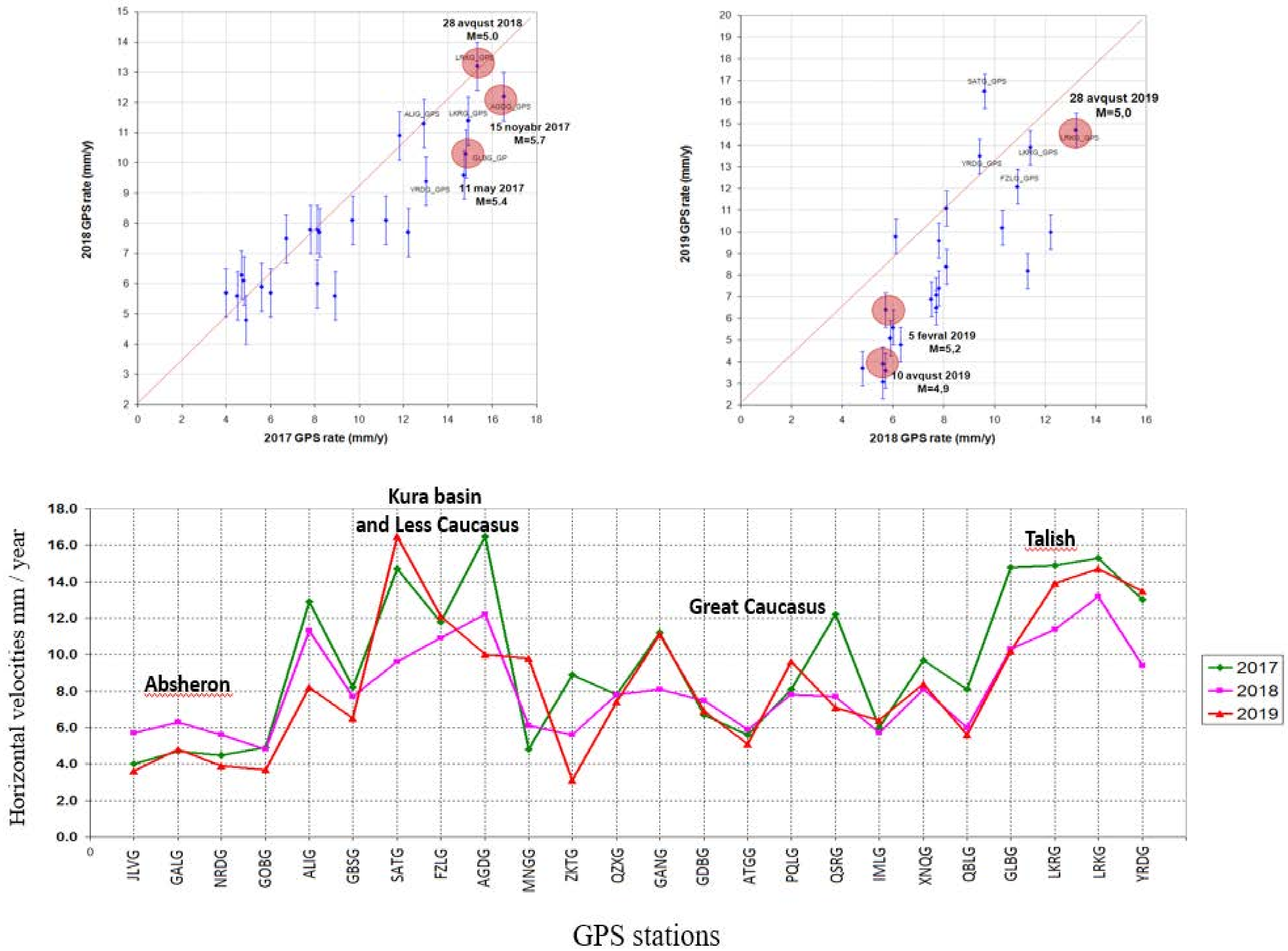

Fig. 2. Graphs of the dependence of strong earthquakes that occurred in 2017-2019 with the value of the velocities of horizontal movements obtained at the GPS stations /
Рис. 2. Графики зависимости сильных землетрясений, произошедших в 2017-2019 гг. от значений скоростей горизонтальных движений, полученных на станциях GPS

3.0) earthquakes that occurred in 2018 (Fig. 2).It was found that in 2017, ZKTG, QSRG, SATG, ALIG, LRKG and LRKG stations had the highest velocities, and the most active regions were the Greater Caucasus, Saatli, Talish and the middle part of the Caspian Sea. LKRG, LRKG, GLBG, ALIG, FZLG and AGDG stations have been assigned the highest velocities in 2018. In 2018, the highest magnitude (ml>5.0) earthquakes occurred in Zagatala and Lerik regions. Taking this into account, it can be said that the most seismically active regions in 2017-2018 were the Greater Caucasus, Saatli and Talish regions. The Zagatala earthquake which occurred at 22:40:27 by local time, 16 km south of Zagatala station (ml = 5.5) and Talish earthquake which occurred at 16:57:14 by local time at 13 km west of Lankaran station was felt at the epicenter up to 6 points. Note that in 2018, the velosity values at the LRKG GPS station reached 13.2 mm/y. (fig. 2). The GAMIT program for 24 GPS stations purchased in 2018 shows a diagram of the velocities and azimuth angles of horizontal displacements. As can be seen from the figure, the velocities at all stations vary between 1-14 mm/year, and the azimuth angles vary between 11-140 degrees.

In 2019, 1.5-3 mm north-northwest movements are recorded in the Greater and Lesser Caucasus, and 1.5-2.5 mm north-east movements are recorded in the Middle and Lower Kura basin (Fig. 3, 4). Also, the values of displacement at the station located on the island of Gilov in the Caspian Sea were set at 5.7 mm.

Separate velocities were also calculated for each station. Compared to 2018, it was determined that from 24 GPS stations, PQLG, XNQG, IMLG, QZXG, GANG, MNGG,

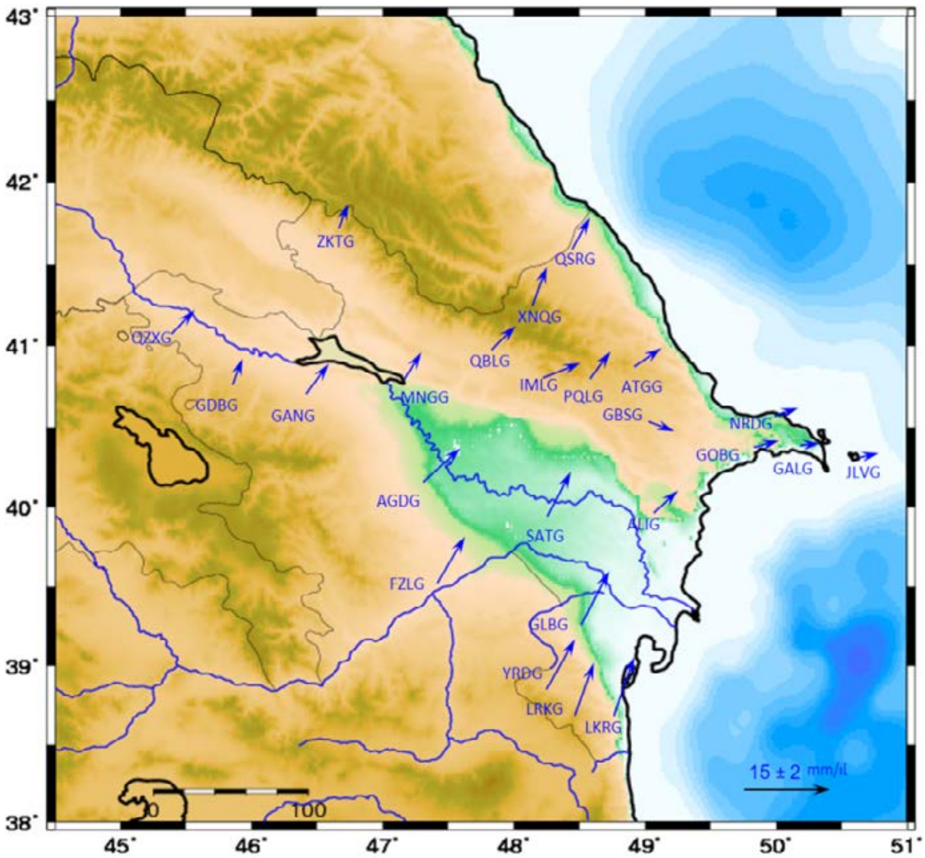

Fig. 3. Vectors map of horizontal movements according to GPS stations for 2017-2019 yy /
Рис. 3. Векторная карта горизонтальных перемещений по станциям GPS за 2017-2019 гг.

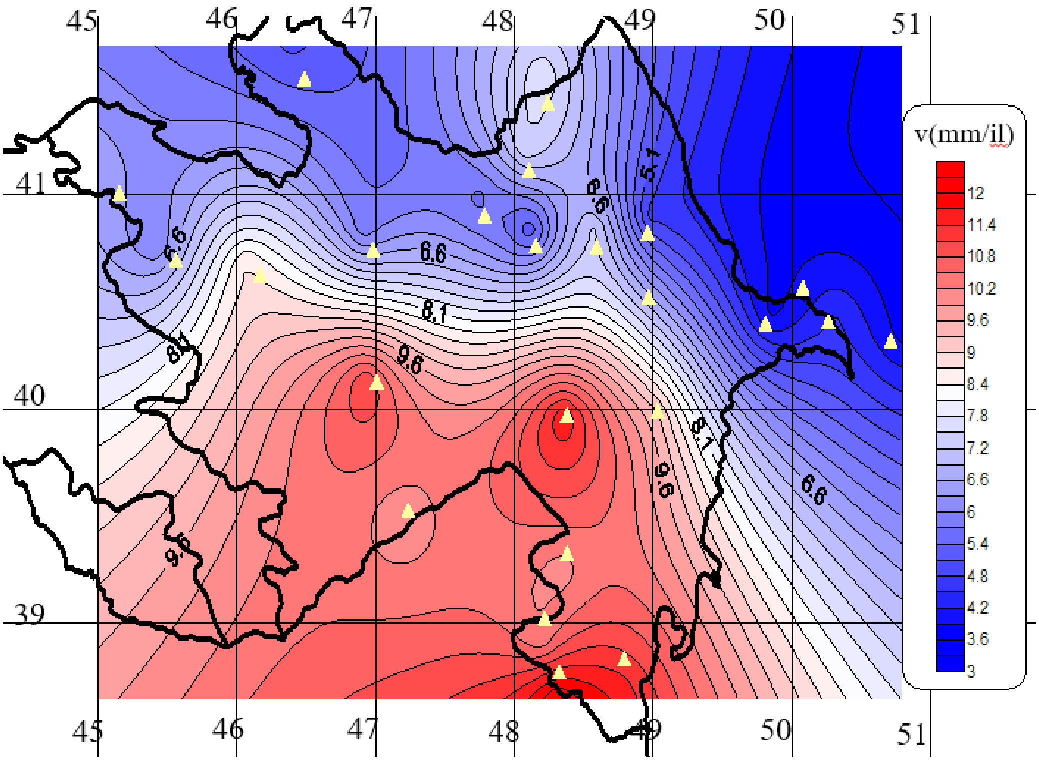

Fig. 4. Map of the distribution of horizontal movement velocities according to GPS station data for the 2017-2019 /
Рис. 4. Карта распределения скоростей горизонтального движения по данным GPS-станций за 2017-2019 гг.

FZLG, SATG, LKRG, LRKG and YRDG stations, the values of horizontal velocities increased by 0.5-7.0 mm/year, ZKTG, QBLG At QSRG, ATGG, GDBG, AGDG, ALIG, JLVGG, GALG, GOBG and NDRG stations, the velosity values decreased by 0.5-3.1 mm/year. In 2019, the highest velocities were observed at Ganja, Mingachevir and Saatli stations. On average, velocities were 3.1-9.6 mm/year in the Greater Caucasus, 6.9-16.5 mm/year in the Kura Basin, 10.2-14.8 mm/year in the Talish area and on the Apsheron Peninsula. It varies between 3.6-4.8 mm / year. Thus, on the basis of data obtained in 2019, an average of 8.4 mm/year north-east movements are observed for the territory of Azerbaijan.

In 2019, the earthquakes with the highest magnitude (ml≥5.0) occurred in Zagatala (ml=4.9) and Ismailli (ml=5.2) regions. In addition, it should be noted that in 2019, high seismicity was detected in the Lesser Caucasus, Talish zone and the Caspian Sea.

In order to monitor the change of velocities depending on the different regions, two profiles were constructed, 1-1 and 2-2 in the direction of SW-NE (Fig. 5). The 1-1 profile is based on 11 stations. As in previous years, the values of velocities in the Lesser Caucasus and the Kura Basin vary from 10 to 16 mm / year, and in the Greater Caucasus from 6 to 9 mm/year. Profile 2-2 is set up at 10 stations, and as can be seen in the figure, the Talish zone is characterized by the highest velocities, but when crossing the territory of Apsheron, the velocities drop almost 3 times. The analysis of the azimuth angles of these stations showed that the directions of the stations located in the Talish region are directed to the EMS, while the values of the azimuth angles of the Apsheron stations increase from 40º to 80 Tal-120º in the Talish zone and in the east-southeast direction. Based on

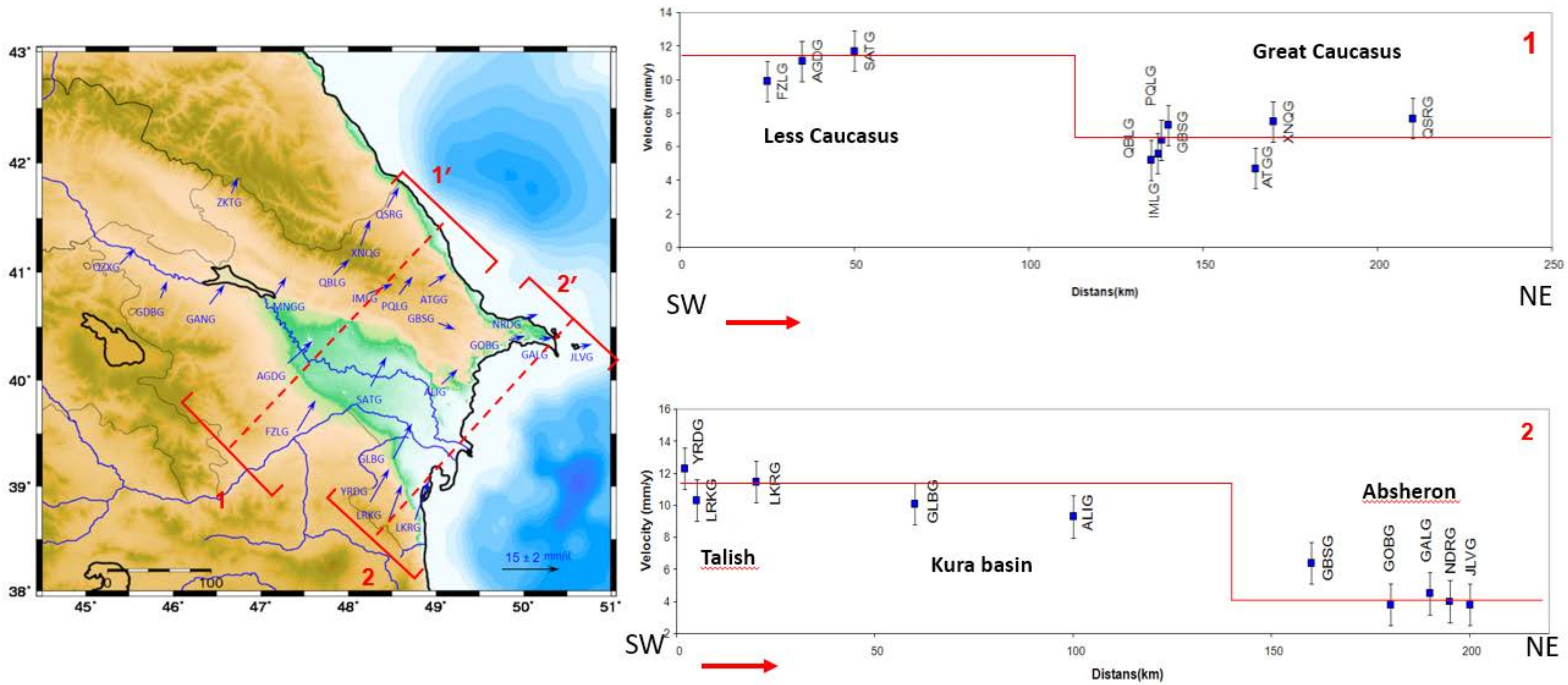

Fig. 5. Map of vectors of horizontal movements and two profiles in the direction SW-NE /
Рис. 5. Карта векторов горизонтальных перемещений и два профиля в направлении ЮЗ-СВ

this, it can be said that under the influence of the northern drift of the Arab-Iranian plates [McKenzie, 1970, 1972, 1978; Mahmoud, 2005], the Lesser Caucasus and Talish regions move from south to north-east as a single plate with horizontal movements and move clockwise in the Apsheron region at 3-5 mm/year.

It should be noted that as a result of the analysis of data obtained from the Institute of Geology and Geophysics and the RSSC during 1998-2019, a new map of the distribution of horizontal crustal movements for Azerbaijan and neighboring areas was compiled. The compiled GPS velosity map (horizontal movements of the Earth's crust), the database of the results of their processing and analysis are attached to the regional archive and can be used for applied research in the territory of the Republic of Azerbaijan, including engineering seismology.

Results

Modern geodynamic conditions of the territory of Azerbaijan for 2017-2019yy were analyzed on the basis of space geodesy GPS and seismological data. One of the most pronounced features of the GPS velocity field is the reduction in the cost of GPS velocity components (northern component VN) perpendicular to the direction of extension of the Greater Caucasus Surface from south to north. The north-northeast movement of the earth's surface is interpreted as one of the reasons for this accumulation of tension. In addition, there is a tendency for horizontal movement in the Kura Depression and the Lesser Caucasus, which is reflected in the increase in velosity from west to east along the extension of the mountain range. It was determined that the earth's crust shortened at a velosity of ~ 5 mm/year at the Absheron peninsula. The quakes affected Zagatala, Sheki, Ismailli and Shamakhi regions along the southern slope of the Greater Caucasus. In this zone, there is a change in both the direction and value of GPS velocity vectors, which can be explained as the main reason for the accumulation of voltage.

Thus, on the basis of data obtained in 2018, on average, up to 8 mm per year in the north-northeast direction was observed for the territory of Azerbaijan. Separate velocities were also calculated for each station. Compared to 2017, it was determined that out of 24 GPS stations, JLVGG, GALG, GOBG and NDRG stations increased the values of horizontal velocities by 1-1.7 mm/y. Velosity values have dropped at the remaining 20 stations.

Analysis of velocities and azimuth angles of horizontal displacements obtained in the GAMIT program for 24 GPS stations acquired in 2018 showed that the velocities at all stations vary between 1-14 mm / year and azimuth angles between 11-140 degrees, and the most seismically active region is the Talish region. has been published.

In the direction of the Lesser Caucasus Lower Kura Basin (SMG-CS), an increase of up to 6 mm / year is observed. The values of azimuth angles of Apsheron stations increase from 40 to 120-140 and are directed in the east-southeast direction.

During 2019, on average, up to 8.4 mm per year in the north-northeast direction is observed for the territory of Azerbaijan. Separate velocities were also calculated for each station. Compared to 2018, it was determined that out of 24 GPS stations PQLG, XNQG, IMLG, QZXG, GANG, MNGG, FZLG, SATG, LKRG, LRKG and YRDG stations, the value of horizontal velocities increased by 0.5-7.0 mm/year, ZKTG, QBLG. At QSRG, ATGG, GDBG, AGDG, ALIG, JLVGG, GALG, GOBG and NDRG stations, the velocities values decreased by 0.5-3.1 mm/year. In 2019, the highest velocities were observed at Ganja, Mingachevir and Saatli stations. On average, velocities were 3.1-9.6 mm/year in the Greater Caucasus, 6.9-16.5 mm/year in the Kura Basin, 10.2-14.8 mm/year in the Talish area and on the Apsheron Peninsula. It varies between 3.6-4.8 mm/year.

The analysis of the Talish zone showed that the directions of the stations located in the region are moving towards the EMS, while the values of the azimuth angles of the Apsheron stations increase from 40 to 80-120 and are directed in the east-southeast direction.

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