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ORIGINAL PAPER

ESTABLISHING THE CORRELATION BETWEEN THE CHANGES OF ABSOLUTE ROTATION POLES OF MAJOR TECTONIC PLATES BASED ON CONTINUOUS GNSS STATIONS DATA

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ABSTRACT

The purpose of the work is to establish the correlation between the change of absolute rotation poles of major tectonic plates based on continuous GNSS stations data. The work investigates 2804 continuous GNSS stations located on Pacific, North American, Eurasian, African, Antarctic, Australian and South American plates during 2002-2021. The components of recent horizontal displacements of continuous GNSS stations have been determined and a map of their distribution pattern has been constructed. The absolute rotation pole in ITRF2014/IGS14 reference frame of the studied tectonic plates has been determined. The obtained values are in good agreement with modern plate models. The definition of average annual rotation poles has been developed and their analysis has been carried out to research the dynamics of their change in time. It has been established that the change in the average annual rotation poles of the North American, African and South American plates occurs synchronously, while their change is asynchronous to the Pacific plate. Simultaneous changes in the average annual rotation poles of Antarctic and African plates were have also been identified.

INTRODUCTION

Hypothesis of tectonic plates is based on the interaction of processes taking place on the border of two outer shells of the Earth – lithosphere and asthenosphere. Severe deformations of the lithosphere occur in tectonically active areas, which divide the lithosphere into 7 major tectonic plates (Pacific, North American, Eurasian, African, Antarctic, Australian and South American), 13 minor tectonic plates (Somali, Nazca, Indian, Sunda, Philippine Sea, Amurian, Arabian, Okhotsk, Caribbean, Cocos, Yangtze, Scotia and Caroline) and a large number of small mosaic block plates. In the first publications, the Earth was divided into 5-6 plates (Morgan, 1968; Le Pichon, 1968), while in our time, their number has increased up to 56 plates (Argus et al., 2011), 31 additional plates whereof cover 2.8 % of the surface area. Three types of active zones are clearly seen between the lithospheric plates, and they were first described by Morgan in 1968 – these are the zones of spreading (divergent), subduction (convergent) and transform faults.

In the process of mathematical modeling, it is necessary to take into account the following properties of tectonic plates. Firstly, plate boundaries corresponding to active earthquakes are continuous. Large tectonic plates usually correspond to spreading centers, subduction zones, and transform faults. Secondly, the important factor in modeling the motion of tectonic plates is the hypothesis of their hardness, which allows us to use Euler's theorem on the translational-rotational motion of a rigid body to construct fairly simple models of the relative motion of plates in the geosphere. Thirdly, all tectonic plates are considered as hard spherical shells of a certain area on the surface of the sphere, and the spreading velocity is considered as key information to explain their motion. From a modeling point of view, the relative motion between any two tectonic plates can be represented as a simple rotation about the Euler pole, and therefore, Euler parameters play an important role in building tectonic plate motion models.

According to Euler's rotation theorem (Euler, 1776), the motion of a solid body on the surface of a sphere can be described as axial rotation going through the center of the sphere. As noted, Lowrie in 2007, the theorem states that the displacement of a tectonic plate relative to other plates takes place as a rotation about the Euler pole of relative rotation between the plates. Using this theorem, one can find the location of the pole of rotation to fix the tectonic plate in space so that the motion inside the plates can be analyzed. Lobkovsky in 1988 notes that the use of the given theorem in geodynamics gave the concept of plate tectonics a quantitative character and opened the way for theoretical geology to gradually transform from descriptive science into an exact scientific discipline. Obviously, the rotation mode should serve

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as a starting point and basis for numerical and physical modeling of any geological (as well as all other) processes (Khain and Poletaev, 2007), i.e., any research in tectonophysics should begin with an analysis of the role of rotation poles in geodynamic motion. The Euler pole can be located by different methods such as transform fault azimuths, earthquake slip vectors, and spreading rates at mid-ocean ridges (Chase, 1972; Minster and Jordan, 1978; DeMets et al., 1990; Argus and Gordon, 1991). However, Argus and Heflin in 1995, Sella et al. in 2002, Altamimi et al., 2002; Kreemer et al., 2006, Altamimi et al., 2007; Altamimi et al., 2012 and Goudarzi et al., 2015 note that due to the development of GNSS (Global Navigation Satellite Systems), rapid increase in the number of continuous GNSS stations, as well as high quality of their measurements, they are an alternative method for estimating the parameters of the Euler pole. At present, long-term series of observations of continuous GNSS stations located on all continents and a large number of islands have been accumulated. Obviously, based upon these data, it is possible to trace the changes in the rotation poles of tectonic plates over time accurately and analyze their correlation. Also, recently for estimating the parameters of the Euler pole other space measurement techniques, including VLBI (Very Long Baseline Interferometry), SLR (Satellite Laser Ranging) and DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) are actively used. Some examples of the use of VLBI, SLR and DORIS for tectonic plate parameters estimation can be found in Kraszewska et al. (2016, 2018), Jagoda et al. (2019) and Jagoda and Rutkowska (2020a). Altamimi et al. (2016) note that recent solution ITRF2014 is based on the homogeneous reprocessing of the four space techniques SLR, DORIS, VLBI, and GNSS, where the maximum time series available for each geodetic technique were used.

Therefore, this paper aims at determining the rotation poles (the location of the pole of rotation and an angular rotation rate) of tectonic plates based on measurements of continuous GNSS stations over the last 20 years (2002-2021), as well as analyzing the dynamics of changes in rotation poles over time. The study was conducted relative to no-net-rotation reference frame. Argus et al. (2011) note that plate angular velocities (angular rotation rate) in the no-net-rotation reference frame are used by many in the geoscience community including geodynamicists, tectonicists, and geodesists as a standard for assessing the net rotation of the lithosphere and, for example, examining the asymmetry of subduction. According to Argus and Gordon (1991) the no-net-rotation reference frame differs significantly from the hotspot reference frame.

DATA

The starting point for the research was the daily time series solutions of continuous GNSS stations downloaded from the Nevada Geodetic Laboratory website (Blewitt et al., 2018).

The coordinates and time series of the continuous GNSS stations were calculated by Nevada Geodetic Laboratory (2022) using GIPSY-OASIS-II software from Precise Point Positioning in IGS14 reference frames. According to Figurski and Nykiel (2017) a new and revised IGS14 frame has been introduced in 2017 in parallel with the redefinition of the ITRF (ITRF2014) (Altamimi et. al., 2016) including new and updated calibration of satellite and GNSS receivers' antennas. Transformation parameters between ITRF2014 and IGS14 are not published because it is assumed that their global values are zero, and due to the practical identity of these systems we will use the abbreviation ITRF2014/IGS14.

We followed similar but enhanced criteria proposed by Altamimi et al. (2017) for the selection of continuous GNSS stations. The enhancement concerned only one aspect – completeness of continuous GNSS stations time series above 70 %. It is known that GIA (Glacial Isostatic Adjustment) phenomenon has a direct effect on the estimated velocities of continuous GNSS stations in some occurred areas (especially in Antarctic, Eurasian and North American plates). Henton et al. (2006) note that GIA produces horizontal velocities that are typically directed radially outward from regions of highest uplift, but have smaller rates than vertical velocities. In this study we operated with a time series downloaded from the Nevada Geodetic Laboratory website (Blewitt et al., 2018), so we did not additionally use any GIA model and does not consider the GIA horizontal velocity predictions. In occurred areas, we tried to choose continuous GNSS stations not affected by the GIA. The criterion to identify GIA-affected stations is to have modeled vertical velocity of greater than 0.75 mm/yr (Altamimi et al., 2012). As we have set very strict requirements for the daily time series solutions of continuous GNSS stations, this has led to the fact that not all plates have enough data to accurately determine rotation poles. As a result, it has been decided to determine and study the rotation poles of only major tectonic plates based on continuous GNSS stations data in the given paper.

Pacific Plate (PA) – a major oceanic tectonic plate that lies beneath the Pacific Ocean. It is the largest tectonic plate with an approximate area of 103,280,000 km^2 (Brown and Wohletz, 2007) (or 2.57685 steradians). 186 continuous GNSS stations have been selected to determine and study the rotation poles of the PA plate.

North American Plate (NA) – a major tectonic plate including most of North America, Greenland and part of Siberia. With an approximate area of 75,888,000 km^2 (Brown and Wohletz, 2007) (or 1.36559 steradians), it is the Earth's second largest tectonic plateau. 965 continuous GNSS stations have been selected to determine and study the rotation poles of the NA plate.

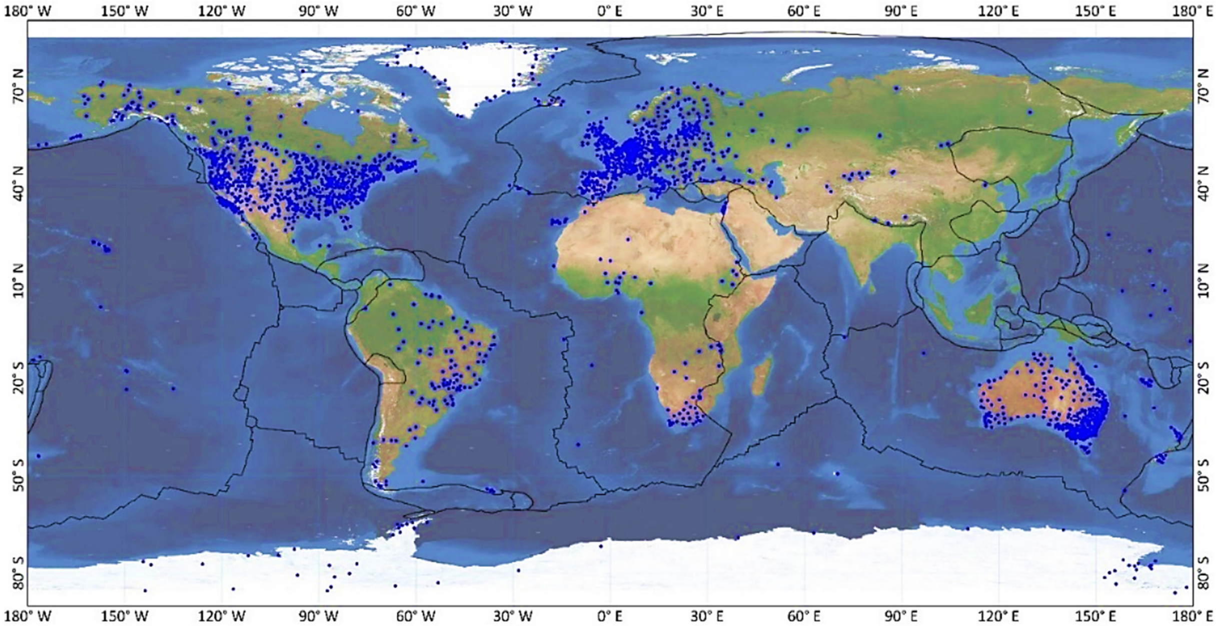

Fig. 1 GNSS stations network (The map was compiled using plate boundaries of Bird (2003), coordinates were obtained from Nevada Geodetic Laboratory (2022).

Eurasian Plate (EU) – a major tectonic plate which includes most of the continent of Eurasia (a landmass consisting of the traditional continents of Europe and Asia), with the notable exceptions of the Indian subcontinent, the Arabian subcontinent, and the area east of the Chersky Range in East Siberia. It also includes oceanic crust extending westward to the Mid-Atlantic Ridge and northward to the Gakkel Ridge. The EU plate has an area of about 67,811,000 km^2 (Brown and Wohletz, 2007) (or 1.19630 sterradians). 882 continuous GNSS stations have been selected to determine and study the rotation poles of the EU plate.

African Plate (AF) – a major tectonic plate underlying Africa west of the East African Rift. Approximate area of this plate is 61,334,000 km^2 (Brown and Wohletz, 2007) (or 1.44065 steradians). It should be noted that since the continent of Africa consists of a crust from both the AF and the Somali plates, some literature refers to the AF plate as the Nubian plate to distinguish it from the continent as a whole (Chu and Gordon, 1999). 126 continuous GNSS stations have been selected to determine and study the rotation poles of the AF plate.

Antarctic Plate (AN) – a major tectonic plate including the continent of Antarctica, the Kerguelen Plateau and extending outward under the surrounding oceans. The AN plate has an area of about 60,916,000 km^2 (Brown and Wohletz, 2007) (or 1.43268 steradians). 58 continuous GNSS stations have been selected to determine and study the rotation poles of the AN plate.

Australian Plate (AU) – a major tectonic plate underlying the continent of Australia, Tasmania, as well as parts of New Guinea, New Zealand, and the Indian Ocean basin, with the notable exceptions of the Indian subcontinent. Approximate area of this plate is 47,152,000 km^2 (Brown and Wohletz, 2007) (or 1.13294 steradians). 475 continuous GNSS stations have been selected to determine and study the rotation poles of the AU plate.

South American Plate (SA) – a major tectonic plate which includes most of South America and a large part of the south Atlantic. The SA plate has an area of about 43,617,000 km^2 (Brown and Wohletz, 2007) (or 1.0305 steradians). 112 continuous GNSS stations have been selected to determine and study the rotation poles of the SA plate.

A total of 2804 continuous GNSS stations have been selected for processing. The distribution of all selected stations is shown in Figure 1. The networks characteristics are shown in Figure 2.

Analyzing the presented graphs (see Fig. 2a), we can trace the growth in the number of stations in each network over time, which is directly related to the development and popularization of GNSS technologies. Analysis of graphs (see Fig. 2b) confirms the heterogeneity of observations over time. For example, the longest time series are 20 years and the shortest are 3 years. Most observations last for 5–15 years. However, since 2010, the time series of almost all stations have been homogeneous and continuous.

METHOD

The provided time series of daily solutions of continuous GNSS stations have been used to determine the components of the velocity vectors of

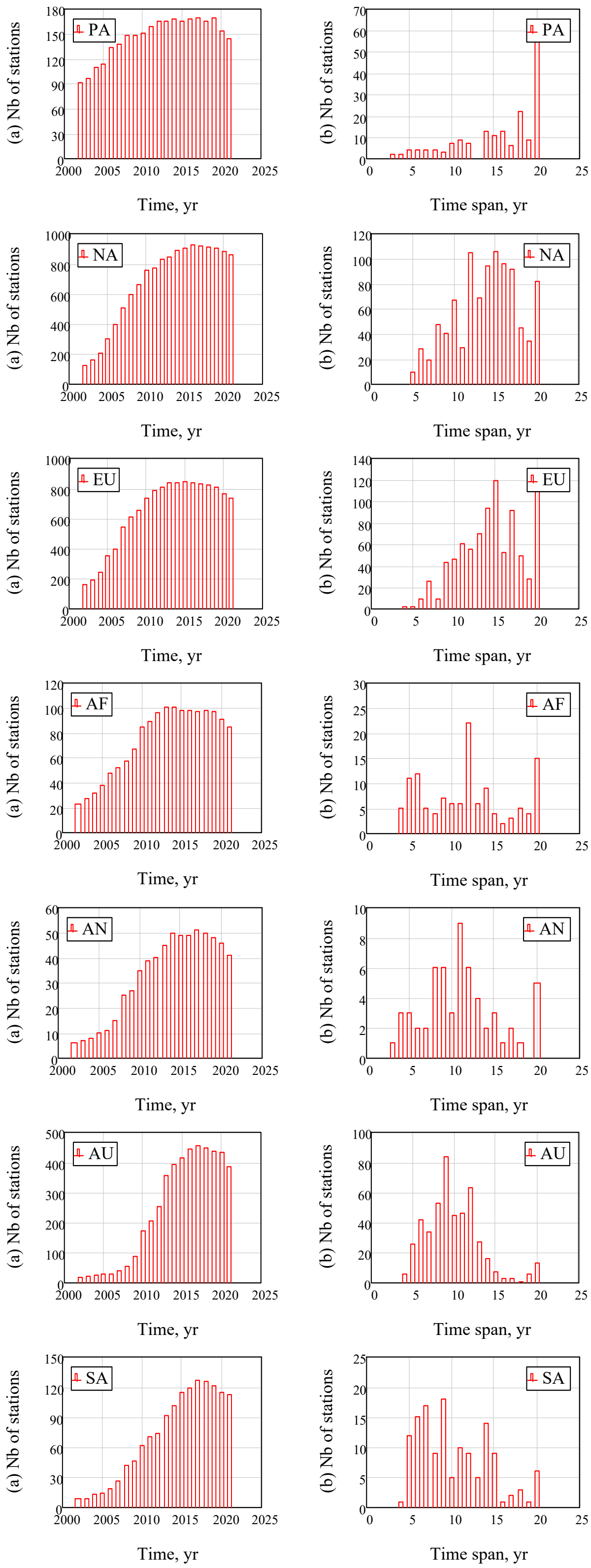

Fig. 2 Networks characteristics in terms of (a) station availability over time and (b) station time span.

recent horizontal displacements v_B and v_L. For each solution, linear equations of the following form have been composed:

$$f(t_i) = v(t_i - t_0) + y_0, \tag{1}$$

where, t_i – epoch of observation, v – the linear velocity of the station (respectively v_B and v_L) and y_0 – the intercept (at epoch t_0 – initial epoch).

The systems of equations for each component have been solved by the least square technique, the components of the velocity vectors of horizontal displacements v_B and v_L have been determined, and the accuracy of the determined parameters m_{v_B} has been m_{v_L} estimated.

Given the fact that observations are heterogeneous in time (see Fig. 2), it is necessary to use the weight of observations. Therefore, in the next step, a weight is determined for each solution, and it depends on the continuity and uniformity of data distribution during observations (Tretyak et al., 2018):

$$p = \frac{p_1 \cdot p_2}{m_v{}^2}, \tag{2}$$

where p_1 – weight for data irregularity, p_2 – weight for continuity of data, $m_v{}^2$ – mean square error of determining velocity vector components of horizontal displacements.

The weight for data irregularity is determined in the following way:

$$p_1 = 1 - \frac{2 \cdot |s_r - s_t|}{\Delta t}, \tag{3}$$

where $s_r = \frac{t_0 + t_k}{2}$ – an average length of whole observation interval independent of the number of solutions, t_k – an epoch of the end of observation, $s_t = \frac{\sum_{i=1}^{n} t_i}{n}$ – an average epoch of all existing solutions, n – a number of solutions that can be different from the average length of observation interval s_r, $\Delta t = t_k - t_0$ – observation interval length.

The weight for data continuity is determined in the following way:

$$p_2 = 1 - \frac{4 \cdot \left|\frac{\Delta t}{4} - \delta t\right|}{\Delta t}, \tag{4}$$

where $\delta t = \frac{\sum |t_i - s_t|}{n}$ – the sum of mean deviations of the epochs of all available solutions of s_t.

The relationship between velocity vector components of horizontal displacements and rotation poles may be represented by the following formulas (Drewes, 1990):

$$\begin{aligned} v_B &= \omega \cdot cos(\phi) \cdot sin(L - \lambda) \\ v_L &= \omega \cdot (sin(\phi) - \\ &\quad - cos(L - \lambda) \cdot tg(B) \cdot cos(\phi)) \end{aligned} \tag{5}$$

where ω – angular velocities of the tectonic plate; ϕ, λ – coordinates of the rotation pole; B, L – coordinates of the permanent GNSS station. There is a double number of equations within the given system, so the number of equations is always bigger than the number of unknowns.

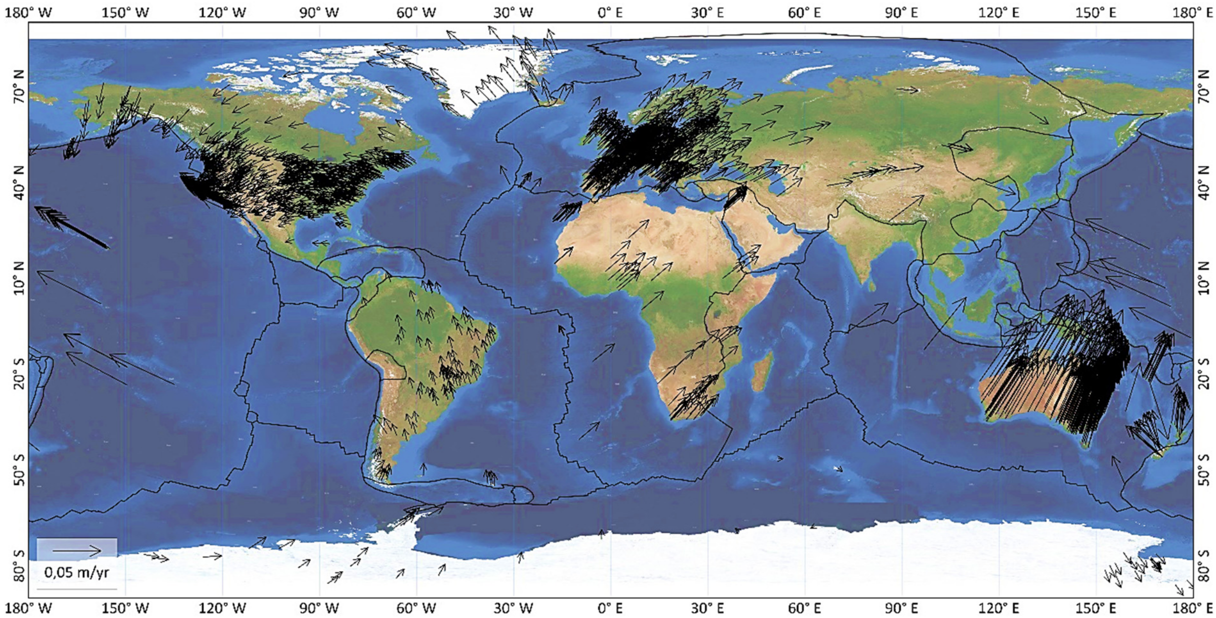

Fig. 3 Map-scheme of the velocity distribution of recent horizontal displacements of continuous GNSS stations (The map was compiled using plate boundaries of Bird (2003).

For each determined velocity vector component of the recent horizontal displacements v_B та v_L with the corresponding weights p, the equation is composed. Solving a built-up system of equations using the least square technique, we determine the rotation poles (ω, ϕ, λ), as well as evaluate the accuracy of such measurements. All calculations of rotation poles were performed using software based on a least squares adjustment procedure that was developed by the author in MathCAD15.0 software.

RESULTS

Using the proposed method, the components of the velocity vectors of recent horizontal displacements of continuous GNSS stations of major tectonic plates, for the period of 2002-2021 in ITRF2014/IGS14 reference frame have been determined. The distribution of the determined velocities is presented in Figure 3.

Analyzing the above map-scheme, it can be noted that continuous GNSS stations that are located on the EU, AF, AN and AU plates are characterized by a north-east motion direction, but the horizontal velocity of their motion differs.

Thus, for the EU plate the recent horizontal velocity is 17–46 mm/year, for the AF plate – 18–31 mm/year, for the AN plate – 4–22 mm/year, and for the AU plate – 35–70 mm/year. In contrast, continuous GNSS stations located on the SA plate are characterized by a northerly direction of motion with a recent horizontal velocity of 9-24 mm/year, the PA plate – a northwestern direction of motion at a velocity of 32-77 mm/year, and the NA plate – a western direction of motion with a velocity of 6-31 mm/year.

The obtained rates of recent horizontal displacements of continuous GNSS stations have been used to determine the rotation poles of the studied tectonic plates for the period of 2002-2021 in ITRF2014/IGS14 reference frame (Table 1). It should be noted that relative to no-net-rotation reference frame each plate rotates counterclockwise.

Analyzing the presented results, it can be noted that the accuracy of determining the angular velocities is by two orders lower than the velocity value. The accuracy of determining the latitude is within the range of 0.04-0.6, while the accuracy of determining the longitude is lower and within the range of 0.1-1.4 degrees. Angular velocities of PA and AU plates are significantly higher than the velocity of other plates under study. This is directly related to the horizontal displacement velocities of continuous GNSS stations (see Fig. 3). AU plate is characterized by the highest accuracy of determination of coordinates of the rotation pole, which further confirms its tectonic stability. Instead, the lowest accuracy of determination of coordinates of the rotation pole is inherent in the SA plate.

In general, the obtained values of accuracy are close to the results obtained by Argus et al. (2011), Altamimi et al. (2017), Jagoda and Rutkowska (2020b) and Jagoda (2021).

The accuracy of determining the components of the velocity vectors of recent horizontal displacements is within the range of 1.1-5.5 mm, and averages 10 % of the vector length.

The location of the identified rotation poles is shown in Figure 4, additionally the presented figure is supplemented by rotation poles determined in Argus and Gordon, 1991; Drewes, 1998; Altamimi et al., 2002; Sella et al., 2002; Drewes, 2009; Argus et al., 2011; Altamimi et. al., 2017; Jagoda and Rutkowska, 2020b and Jagoda, 2021. Analyzing the presented

Table 1 Absolute rotation poles of major tectonic plates over the period of 2002-2021 (ITRF2014/IGS14 reference frame).

Plate	ω, °/yr	ϕ, °N	λ, °E	Displacement velocity accuracy m_v, mm
PA	0.679±0.007	–62.935±0.329	95.638±0.961	5.5
NA	0.180±0.002	–11.766±0.614	–88.722±0.244	2.2
EU	0.278±0.001	56.885±0.227	–94.120±0.472	1.6
AF	0.284±0.001	48.949±0.213	–80.786±0.519	1.1
AN	0.218±0.002	58.277±0.348	–126.531±0.417	1.3
AU	0.656±0.001	32.648±0.043	36.952±0.098	3.6
SA	0.126±0.001	–18.569±0.531	–130.232±1.434	1.5

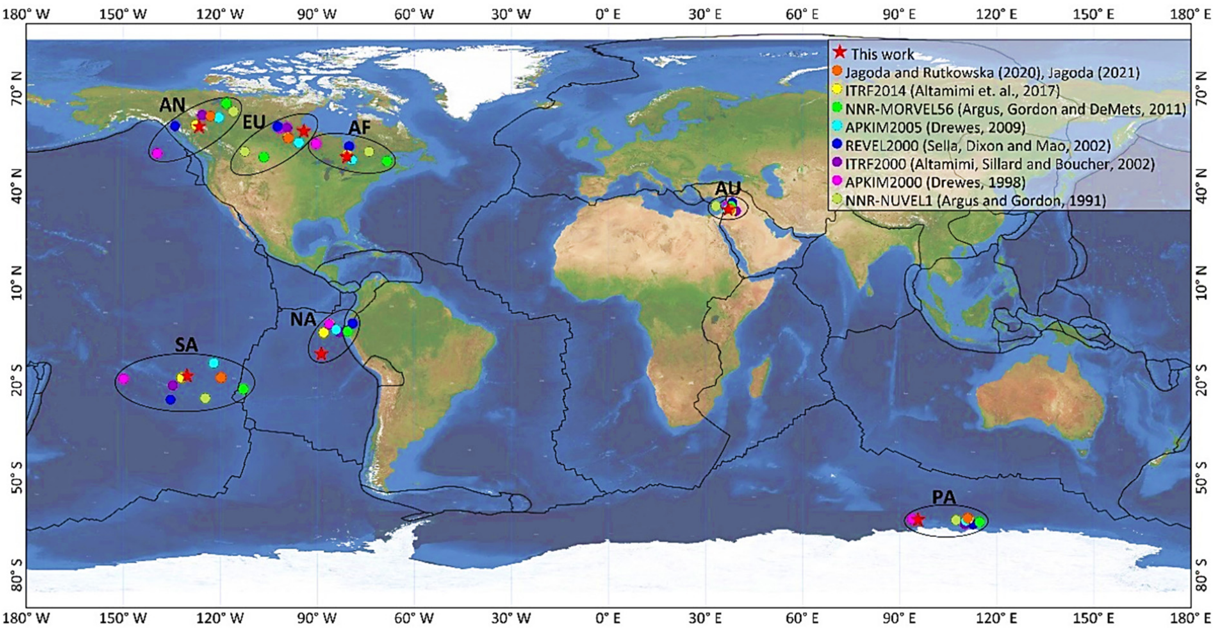

Fig. 4 The location of the identified rotation poles (The map was compiled using plate boundaries of (Bird, 2003).

figure (see Fig. 4), it can be traced that the results obtained (see Table 1) correlate well with the known works.

For a more detailed analysis, Table 2 shows a rotation poles differences between this work and other known works

Analyzing the presented differences, we can state that there is a good agreement with all works which lends support to the validity of the chosen method, and also the reliability of the results obtained. The best agreement is with the works of Altamimi et al. (2017), Jagoda and Rutkowska (2020b) and Jagoda (2021). Obviously, this is due to the fact that other works are based on older data, so they are a bit outdated. The RMS value of the angular velocity difference is in the range of 0.014–0.031°/yr. The RMS value of the latitude difference is in the range of 1.61–5.33°. The RMS value of the longitude difference is in the range of 6.28–12.59°. The highest agreement identified with AU plate, and the lowest with SA and PA plates.

Additionally, the calculation of the average annual rotation poles of major tectonic plates has been

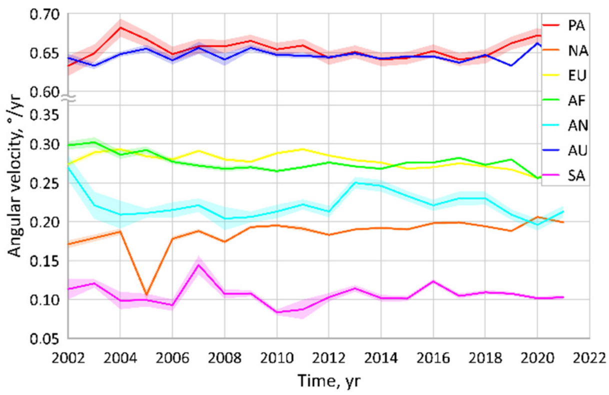

Fig. 5 The change in the average annual rotation poles during 2002-2021 in terms of angular velocities.

made to study the dynamics of their change over time. Figures 5 and 6 show the change in the average annual rotation poles of major tectonic plates during 2002-2021.

Average annual rotation poles are characterized by poorer accuracy of determination (approximately 2-5 times lower compared to Table 1). This accuracy

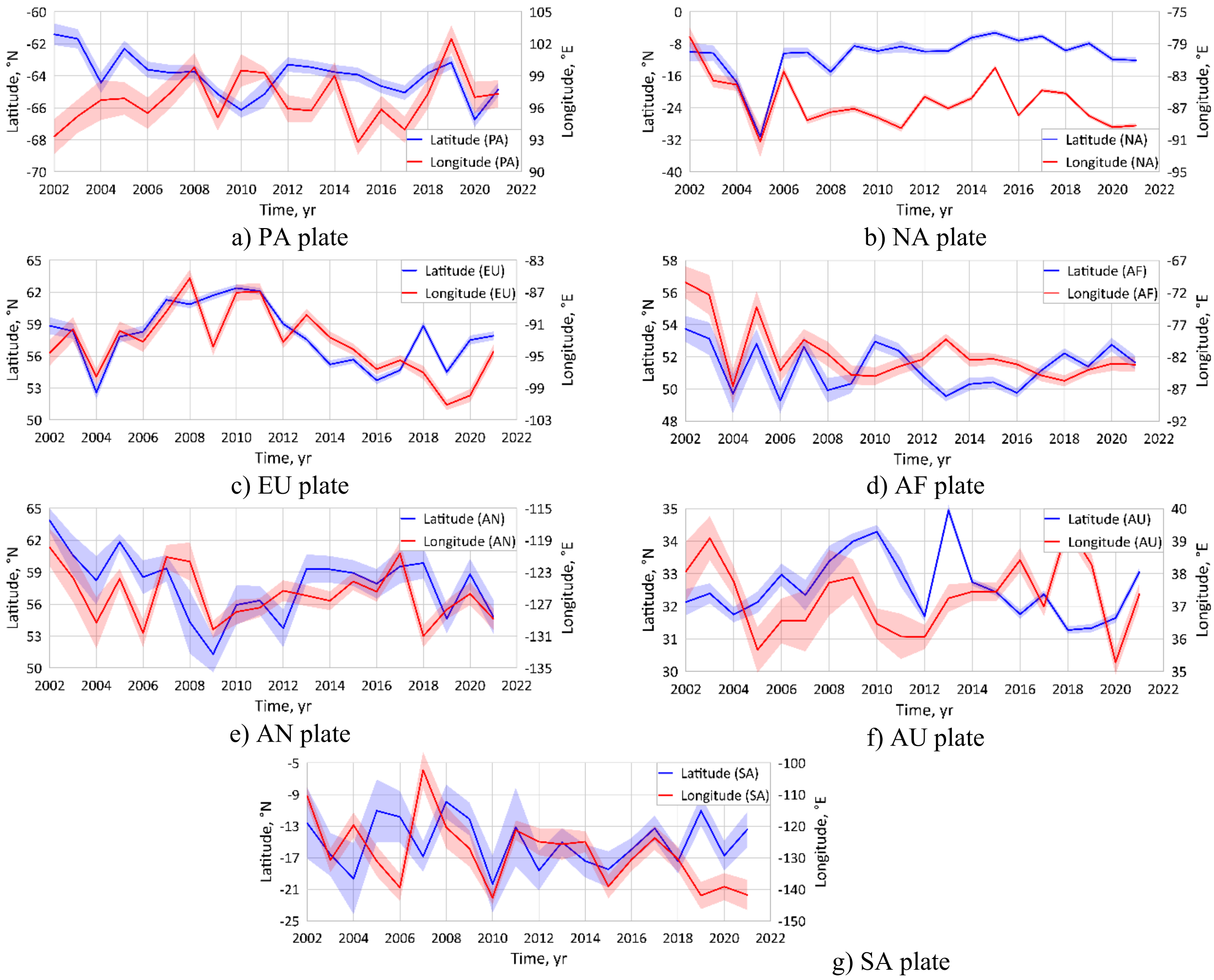

Fig. 6 The change of average annual rotation poles of major tectonic plates during 2002-2021 in terms of location of the pole of rotation.

directly depends on the quality of the data in each year. These graphs confirm the presence of rotation poles migration, as the values of the displacements are much greater than the accuracy of their determination. The presented results (see Figs. 5 and 6) are quite difficult to analyze because they contain abrupt changes in values. Therefore, to simplify the comparison process, correlation coefficients between the determined rotation poles have been calculated for different plates (Table 3).

Since the rotation axis intersects the earth's surface in two places according to Cox and Hart (1986) in this work we present the pole that provides a positive rotation angle determined using right hand rule. But to determine the correct correlation, we used rotation poles without taking into account the right hand and left hand rules. According to Schober et al. in 2018, correlation in the broadest sense is a measure of an association between variables and in correlated data, the change in the magnitude of one variable is associated with a change in the magnitude of another variable, either in the same (positive correlation) or in the opposite (negative correlation) direction. In this study, we used the Pearson correlation coefficient, which is typically used for jointly normally distributed data.

Thumb rule (Hinkle et al., 2003) for interpreting the size of the correlation coefficient has been used. The analysis results show that there is a moderate/strong positive correlation (from +0.57 to +0.86) between the change of the average annual rotation poles of NA, AF, AN and SA plates, while these plates have a moderate/strong negative correlation (from –0.60 to –0.83) with PA plate.

Therefore, the change of the average annual rotation poles of the NA, AF, AN and SA plates occurs synchronously, while their change is asynchronous to the PA plate. Additionally, it can be assumed that asynchronous to the PA and EU plates and synchronous to the NA, AF, AN and SA plates, changes in average annual rotation poles are also characteristic of the AU plate, but they are characterized by weak/moderate correlation. Negligible correlations are observed between the other plates.

Table 2 Rotation poles differences between this work and other works.

Work	Rotation pole	Plate							RMS
		AF	AN	AU	EU	NA	PA	SA	
Jagoda and Rutkowska, 2020b, Jagoda, 2021	ϕ, °N	0.20	3.26	0.29	–2.08	–	0.48	–0.46	1.61
	λ, °E	–0.03	3.52	0.75	–4.84	–	15.37	10.45	7.98
	ω, °/yr	–0.017	0.023	–0.032	–0.020	–	–0.012	–0.009	0.020
ITRF2014 (Altamimi et. al., 2017)	ϕ, °N	0.74	0.57	–0.29	–1.82	6.58	0.33	–0.53	2.62
	λ, °E	–0.05	–0.90	1.10	–4.97	0.70	15.70	–1.66	6.28
	ω, °/yr	–0.017	0.001	–0.025	–0.017	0.014	0.000	–0.007	0.014
NNR-MORVEL56 (Argus et al., 2011)	ϕ, °N	–1.27	7.14	1.21	–8.04	6.92	–0.64	–4.05	5.12
	λ, °E	12.35	8.42	0.99	–12.38	8.08	19.06	17.40	12.59
	ω, °/yr	0.008	0.032	–0.024	–0.055	0.029	–0.028	–0.017	0.031
APKIM2005 (Drewes, 2009)	ϕ, °N	–0.85	2.82	0.15	–3.49	7.47	–0.27	3.97	3.63
	λ, °E	1.49	6.03	–0.25	–1.58	4.52	14.86	8.23	7.07
	ω, °/yr	–0.005	0.025	–0.017	–0.019	0.014	–0.062	–0.003	0.028
REVEL2000 (Sella et al., 2002)	ϕ, °N	3.30	0.20	2.21	1.39	9.38	–1.27	–7.26	4.78
	λ, °E	0.61	–7.47	1.31	–8.09	9.64	17.10	–5.15	8.74
	ω, °/yr	–0.031	0.008	–0.029	–0.021	0.019	–0.024	–0.020	0.023
ITRF2000 (Altamimi et al, 2002)	ϕ, °N	–	3.55	–0.32	1.08	6.73	–1.24	–2.89	3.39
	λ, °E	–	0.96	2.49	–5.25	5.58	14.56	–4.40	7.04
	ω, °/yr	–	0.013	–0.042	–0.018	0.014	–0.013	–0.013	0.022
APKIM2000 (Drewes, 1998)	ϕ, °N	4.15	–8.18	1.15	1.02	9.17	0.23	–0.83	5.07
	λ, °E	–9.61	–12.97	–0.15	–7.48	2.42	–1.74	–19.67	10.16
	ω, °/yr	–0.004	0.0320	–0.026	–0.008	0.010	0.021	0.004	0.020
NNR-NUVEL1 (Argus and Gordon, 1991)	ϕ, °N	1.65	4.72	1.15	–6.29	9.37	–0.06	–6.73	5.33
	λ, °E	6.79	10.73	–3.75	–18.18	2.82	11.66	5.83	9.88
	ω, °/yr	0.006	0.022	–0.006	–0.048	0.030	–0.039	–0.006	0.028
RMS	ϕ, °N	2.20	4.63	1.08	4.00	8.03	0.71	4.18	–
	λ, °E	6.48	7.59	1.76	9.24	5.66	14.62	10.89	–
	ω, °/yr	0.015	0.022	0.027	0.030	0.020	0.031	0.011	–

Table 3 Correlation dependence between the changes of rotation poles of major tectonic plates during 2002-2021.

Plate	PA	NA	EU	AF	AN	AU	SA
PA	1	0	0	0	0	0	0
NA	–0.65	1	0	0	0	0	0
EU	+0.12	–0.14	1	0	0	0	0
AF	–0.81	+0.68	–0.01	1	0	0	0
AN	–0.83	+0.57	–0.03	+0.86	1	0	0
AU	–0.49	+0.46	–0.32	+0.50	+0.48	1	0
SA	–0.60	+0.57	+0.02	+0.77	+0.67	+0.38	1

CONCLUSIONS AND DISCUSSION

The work presented in this paper was carried out according to quite strict requirements (minimum time span of three years and a completeness of 70 %) to the input data, namely the time series of daily solutions of continuous GNSS stations. Additionally, the concept of weight was used during the observations to take into account the continuity and uniformity of data distribution.

The components of the recent horizontal displacement vectors of 2804 continuous GNSS stations in ITRF2014/IGS14 reference frame located on major tectonic plates for the period of 2002-2021 have been determined and a map of their distribution scheme has been constructed. The accuracy of determining the components of recent horizontal displacement vectors is within the range of 1.1-5.5 mm, and averages 10 % of the vector length.

The obtained components of the recent horizontal displacement vectors of continuous GNSS stations have been used to determine the absolute rotation poles of major tectonic plates in ITRF2014/IGS14 reference frame. The accuracy of angular velocities is 0.001–0.007°/yr and is by two orders lower than the velocity value. The accuracy of determining the latitude is within the range of 0.04–0.6°, while the accuracy of determining the longitude is lower and within the range of 0.1–1.4°. The obtained values are in good agreement with modern plate models.

Calculation and analysis of average annual rotation poles of major tectonic plates have been carried out to study the dynamics of their change over time. The analysis confirmed the migration of the rotation poles of major tectonic plates. It has been established that the change of average annual rotation poles of the NA, AF, AN, SA and AU plates occurs synchronously; however, their change is asynchronous to the PA plate.

The presented algorithm and the obtained values of absolute rotation poles of major tectonic plates can be used to develop new and improve existing models of tectonic plate motion and coordinate systems, as well as to forecast the motion of the Earth's crust on a global scale. A promising direction for further research is the study of absolute rotation poles of medium and small tectonic plates.

The question of the reason for the major tectonic plate rotation poles migration, as well as the physical interpretation of synchronous and asynchronous changes in their value, remains debatable. According to the authors, such phenomena are related to the recent plate convergence and divergence processes along different sections of the plate boundary.

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