Savchyn, I., & Tretyak, K. (2023). Tectonic plates moment of inertia and angular momentum determination: the case of the Antarctic plate. *Ukrainian Antarctic Journal*, *21*(1), 13—23.
https://doi.org/10.33275/1727-7485.1.2023.704

I. Savchyn*, K. Tretyak
Lviv Polytechnic National University, Lviv, 79013, Ukraine
*** Corresponding author:** ih.savchyn@gmail.com

Tectonic plates moment of inertia and angular momentum determination: the case of the Antarctic plate

Abstract. The main goal of this study is to develop and test an algorithm for determining the moment of inertia and angular momentum of a tectonic plate based on the processing of time series of daily solutions of continuous GNSS (Global Navigation Satellite System) stations. The proposed algorithm consists of four consecutive stages: reformatting data to the internal format; dividing the plate into cells and determining their masses; determining the rotation poles and distances from cells to the poles; calculating the plate's moment of inertia and angular momentum. The algorithm uses freely available time series of daily solutions from continuous GNSS stations or any other data prepared in a similar format. The algorithm is tested for determining the moment of inertia and angular momentum of the Antarctic plate based on the processing of time series of daily solutions of continuous GNSS stations for the period 1995—2021. It is confirmed that the Antarctic Plate's rotation poles, moment of inertia, and angular momentum are dynamic parameters. However, additional calculations and in-depth comprehensive analysis are required to determine the causes of such dynamics. As a result of comparing, the dynamics of changes in the Antarctic Plate's rotation poles partially compensate for the unevenness of the Earth's rotation to keep the angular momentum of the Earth constant.

Keywords: Earth's crust movements, GNSS data, mathematical modeling, rotation poles

1 Introduction

The processes of tectonic plate movement are of considerable scientific interest, important for understanding geological processes, earthquakes, mountain ranges, and other geological phenomena. In recent years, long-term time series of daily solutions of continuous GNSS (Global Navigation Satellite System) stations have been actively used to study them (Atanasova-Zlatareva, 2014; Saria et al., 2014; Vassileva & Atanasova, 2014; Vassileva & Atanasova, 2016; Zhou et al., 2016; Li et al., 2019; Dimitrov & Nakov, 2022; Savchyn, 2023). The interest in such data is driven by the high quality of geodynamic processes' determination due to the fairly dense networks of continuous Global Navigation Satellite System (GNSS) stations on all continents (Blewitt et al., 2018) and the ever-increasing, and already high, accuracy of satellite measurements. Last but not least, most of the data are freely available. There are enough examples of GNSS measurements used to study geodynamic processes on major, minor, and microplates, for example, for the Eurasian Plate in Zhou et al. (2016), Li et al. (2019), Dimitrov and Nakov (2022), for the African Plate in Saria et al. (2014), Savchyn (2023), for the North American Plate in Calais et al. (2006), for the South American Plate in Xiang et al. (2022) and of course, this list of publications can be extended.

It is interesting to use long-term time series of daily solutions of continuous GNSS stations to study the rotation poles of tectonic plates. The basis of such research is Euler's rotation theorem (Euler, 1776): the motion of a solid body on the surface of a sphere can be described as rotation about an axis passing through the centre of the sphere. Lobkovsky and Kerchman (1991) note that this theorem in geodynamics gave the concept of plate tectonics a quantitative character and opened the way for theoretical geology to gradually transform from a descriptive science into an exact scientific discipline. Modern methods of using GNSS measurements to study the rotation poles of tectonic plates are presented in Marchenko et al. (2012), Altamimi et al. (2017), Tretyak et al. (2018), Jagoda (2021), Savchyn (2022a; 2022b; 2022c), and Savchyn et al. (2023). In fact, using GNSS measurements, it is possible to find the location of the pole of rotation to fix the tectonic plate in space, as well as the angular velocity to understand the dynamics of its movement around this location. The availability of rotation poles makes it possible to analyze and predict movements within the plates and develop models of tectonic plate movements and coordinate systems.

Movements of tectonic plates are known to lead to changes in rotation poles; for example, Savchyn (2022a) presents the dynamics of changes in the rotation poles of large tectonic plates (Pacific, North American, Eurasian, African, Antarctic, Australian, and South American). The authors note that the change in the mean annual rotation poles of North American, African, and South American Plates is synchronous. In contrast, their change is asynchronous to the Pacific Plate; a synchronous change in the mean annual rotation poles of the Antarctic and African Plates is also identified. Obviously, synchronous and asynchronous changes in these parameters compensate for each other to keep the Earth's momentum constant since, according to the law of conservation of angular momentum, in a closed system, the geometric sum of angular momentum (total momentum of the system) remains constant under any interactions of the bodies of this system with each other.

Since the rotation poles of tectonic plates are dynamic, their moments of inertia and angular momentum are also dynamic. To analyze and predict the dynamics of their change, as well as to take into account the influence of these dynamics on keeping the Earth's angular momentum constant, it is necessary to develop an algorithm for determining the moment of inertia and angular momentum of a tectonic plate based on the processing of time series of daily solutions of continuous GNSS stations, which have proven to be effective for determining the rotation poles of tectonic plates.

2 Data and methods

The study proposes and implements a mathematical algorithm for determining a tectonic plate's moment of inertia and angular momentum based on the processing of time series of daily solutions of continuous GNSS stations. This algorithm is based on the assertion that any solid can be considered as a system of an infinite number of material points, and the moment of inertia and angular momentum of such a solid are the sum of the moments of inertia and angular momentum of these material points, respectively. The structural block diagram of the proposed algorithm is shown in Figure 1.

Input data. In the proposed algorithm, the input data are the CRUST1.0 model, Bird (2003) tectonic plate boundaries, geographic coordinates, and time series of daily solutions of continuous GNSS stations located within the tectonic plate.

The CRUST1.0 model is a global model that provides information on crustal thickness and density with a resolution of 1° × 1° (Laske et at., 2013). CRUST1.0 consist of less than 40 crustal types. Each of the 1° × 1° cells has a unique 8-layer crustal profile where the layers are: water, ice, upper sediments, middle sediments, lower sediments, upper crust, middle crust, and lower crust. Parameters V_p, V_s and ρ (density) are given ex-

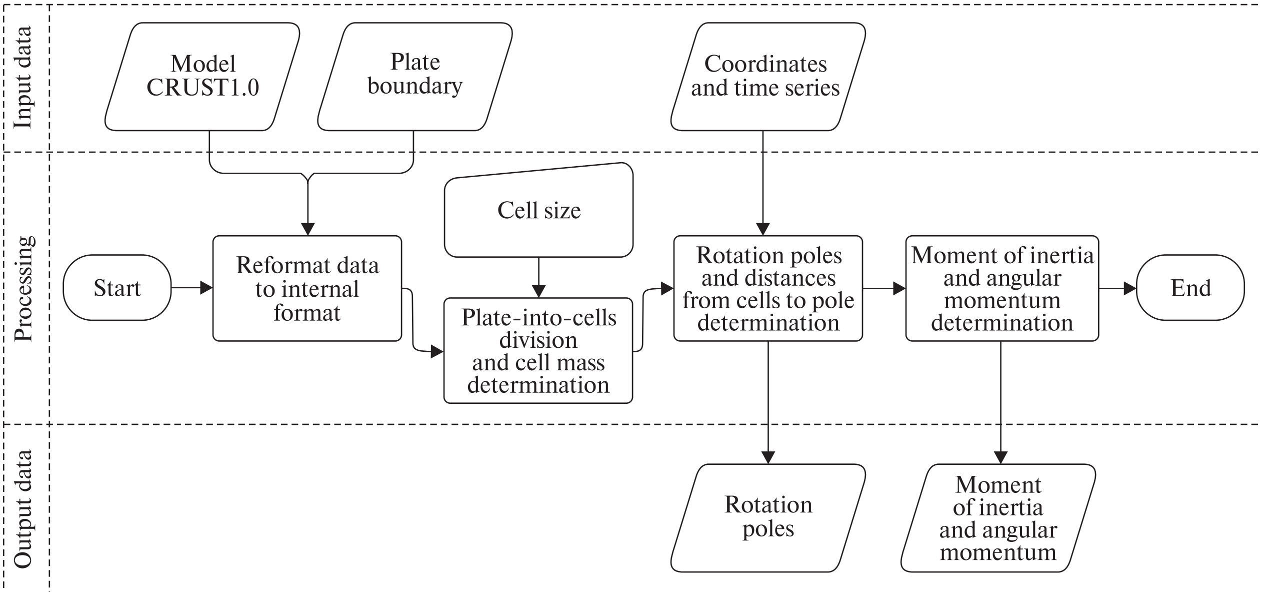

Figure 1. An algorithm for determining the moment of inertia and angular momentum of a tectonic plate based on the processing of time series of daily solutions of continuous GNSS stations

plicitly for these eight layers and the mantle below the Moho (the boundary between the Earth's crust and the mantle). The parameters below the Moho are determined using a modified version of the recent Pn model LLNL-G3Dv3 (Simmons et al., 2012).

The algorithm involves using freely available geographic coordinates and time series of daily solutions of continuous GNSS stations from Nevada Geodetic Laboratory (Blewitt et al., 2018) or any other data prepared in a similar format.

Output data. The output data in the proposed algorithm are the rotation poles and the determined values of the moment of inertia and angular momentum of the tectonic plate.

Structurally, the proposed algorithm involves four main stages:

1) Reformat data to internal format. At this stage, the CRUST1.0 model is prepared, i.e., all data outside the boundaries of the tectonic plate under study are removed. The algorithm uses the tectonic plate boundaries proposed by Bird (2003).

2) Plate-into-cells division and cell mass determination. At this stage, the entire thickness of the tectonic plate is divided into separate cells. Smaller cell sizes allow for a more accurate determination of moments of inertia and angular momentum but increase the processing time.Therefore, in this study, cells with a size of 0.5° × 0.5° × 300 m were used, as this size provides a fairly high accuracy given a not-too-long processing time. For each cell, the spatial coordinates of its center and the mass, which is the product of the volume and the density of the cell obtained from the CRUST1.0 model, are determined. If a cell falls on the boundary of CRUST1.0 layers or the boundary of the model's regular grid, it is divided into several smaller cells.

3) Rotation poles and distances from cells to pole determination.

To determine the rotation poles, we use the mathematical apparatus presented by Marchenko et al. (2012), based on the relationship between the components of the horizontal displacement velocities of continuous GNSS stations and the rotation poles of the plate:

$$v_{B_i} = \omega_P \cdot \cos(\phi_P) \cdot \sin(L_i - \lambda_P),$$
$$v_{L_i} = \omega_P \cdot [\sin(\phi_P) - \cos(L_i - \lambda_P) \cdot \mathrm{tg}(B_i) \cdot \cos(\phi_P)], \quad (1)$$

where, ω_P is the angular velocity of the plate; ϕ_P, λ_P are the coordinates of the pole; L, B are the coordinates of the continuous GNSS station with the defined components of horizontal velocities v_B, v_L.

Equations (1) were compiled for each component of all continuous GNSS stations. The resulting system of equations was solved using the least squares method. It is well known that the quality of the initial data (i.e., in our case, time series of daily solutions of continuous GNSS stations) is key to obtaining a correct and reliable result. Therefore, to solve the system of equations, the weights of measurements were taken into account based on data irregularity and data continuity (Tretyak et al., 2018; Savchyn, 2022a). The use of weights during processing helps to minimise the influence of a single station on the quality of the determined rotation poles.

It is important to note that this algorithm is focused on the long-term time series of daily solutions of continuous GNSS stations, and according to the authors, the effect of seasonality on the values of horizontal velocities will be minimal. Therefore, this algorithm uses a simple model that does not take seasonality into account for determining horizontal velocities:

$$f(t_i) = v(t_i - t_0) + y_0, \quad (2)$$

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

A detailed description and practical application of the algorithm for determining the rotation poles of tectonic plates based on measurements of continuous GNSS stations is presented in Savchyn (2022a; 2022b; 2022c) and Savchyn et al. (2023), and a structural block diagram of this algorithm is provided in Savchyn (2022b).

After determining the rotation poles, the distance from the axis of rotation of the plate to the center of each cell is calculated.

4) Moment of inertia and angular momentum determination. The following dependencies are used to determine the moment of inertia and angular momentum:

$$I_P = \sum_{i=1}^{n} m_i r_i^2, \\ L_P = \sum_{i=1}^{n} m_i r_i^2 \cdot \omega_P = I_P \cdot \omega_P, \quad (3)$$

where I_P is the moment of inertia of the tectonic plate, L_P is the angular momentum of the tectonic plate, n is the number of cells into which the tectonic plate is divided, m_i is the mass of i-th cell, and r_i is the distance from the axis of rotation of the plate to the center of i-th cell.

We decided to test the developed algorithm on the example of the Antarctic Plate. It is a major tectonic plate containing the continent of Antarctica and the Kerguelen Plateau and extending outward under the surrounding oceans. The Antarctic Plate has an area of about 60 916 000 km^2 (Brown & Wohletz, 2007) (or 1.43268 steradians). This plate is particularly interesting because it is the only one within which its own Euler pole passes; also, the Earth's axis of rotation passes through the Antarctic Plate. Due to its polar location, the Coriolis forces cause it to rotate. At the same time, the tectonic plates that cover the equatorial belt are linearly displaced in a westerly direction due to these forces.

Long-term time series of daily solutions of 59 continuous GNSS stations located in the Antarctic Plate were obtained from the Nevada Geodetic Laboratory (Blewitt et al., 2018) to serve as the initial data for the study. The selection of continuous GNSS stations in this study followed the enhanced criteria proposed by Altamimi et al. (2017). Additionally, the study included time series of daily solutions of the ASAV continuous GNSS station, which the authors installed and put into operation near the Ukrainian Antarctic Akademik Vernadsky station between January and April 2019 (Savchyn et al., 2021a; Savchyn et al., 2021b). Figure 2 illustrates the location of the 60 continuous GNSS stations used in this study and their characteristics.

It should be noted that for the selected continuous GNSS stations (see Figure 2a), all available measurements were used for 1995–2021. Due to a rather long research period, the number of stations and the duration of GNSS observations on them are quite heterogeneous (see Figures 2a and 2b). The number of continuous GNSS stations varies from 4 (in 1995) to 53 (in 2016), while the duration of measurements varies from less than five years (FIE0, ARVL, SMR5, SGP5, THRO, and WLRD) to more than 20 years (CAS1, MAW1, SYOG, VESL, DUM1, and CRAR). A detailed description and analysis of the data are presented in Savchyn et al. (2023).

3 Results

Using the proposed algorithm, the values of the annual rotation poles and the annual moments of inertia as well as annual angular momentum of the Antarctic Plate for 1995–2021 were determined (Fig. 3).

According to the results (see Figure 3a), the annual longitude ranges from −130.617 to −118.604° with a standard deviation of 4.548°, and the annual latitude ranges from 51.318 to 67.463° with a standard deviation of 3.715°. The annual values of the Antarctic Plate's angular velocity (see Figure 3b) vary from 0.187 to 0.313°/Myr with a standard deviation of 0.026°/Myr. Standard deviation values were obtained by solving the equations (1) by the least squares method. The obtained values of the rotation poles correlate well with the known models of tectonic plate movements NNR-NUVEL1 (Argus & Gordon, 1991), REVEL2000 (Sella et al., 2002), ITRF2000 (Altamimi et al., 2002), APKIM2005 (Drewes, 2009), NNR-MORVEL56 (Argus et al., 2011), and ITRF2014 (Altamimi et al., 2017). The highest correlation was seen for ITRF2014 (Altamimi et al., 2017).

Analyzing the results obtained (see Figure 3c), it can be noted that the annual values of the Antarctic Plate's moment of inertia vary from $2.4 \cdot 10^{31}$ to $4.4 \cdot 10^{31}$ kg · m^2 with a standard deviation of $3.5 \cdot 10^{26}$ kg · m^2. The annual values of its angular momentum vary from $1.8 \cdot 10^{28}$ to $3.3 \cdot 10^{28}$ kg · m^2 · rad/sec with a standard deviation of $6.7 \cdot 10^{24}$ kg · m^2 · rad/sec. It should be noted that the Antarctic Plate's moment of inertia and angular momentum standard deviation values were obtained based on the theory of errors by defining the standard deviation function based on the standard deviation arguments.

According to the results (see Figure 3), the accuracy of determining the rotation poles is not uniform. This is clearly related to the accuracy and quantity of the initial data and to the development of GNSS technologies in general. Obviously, this fact has an

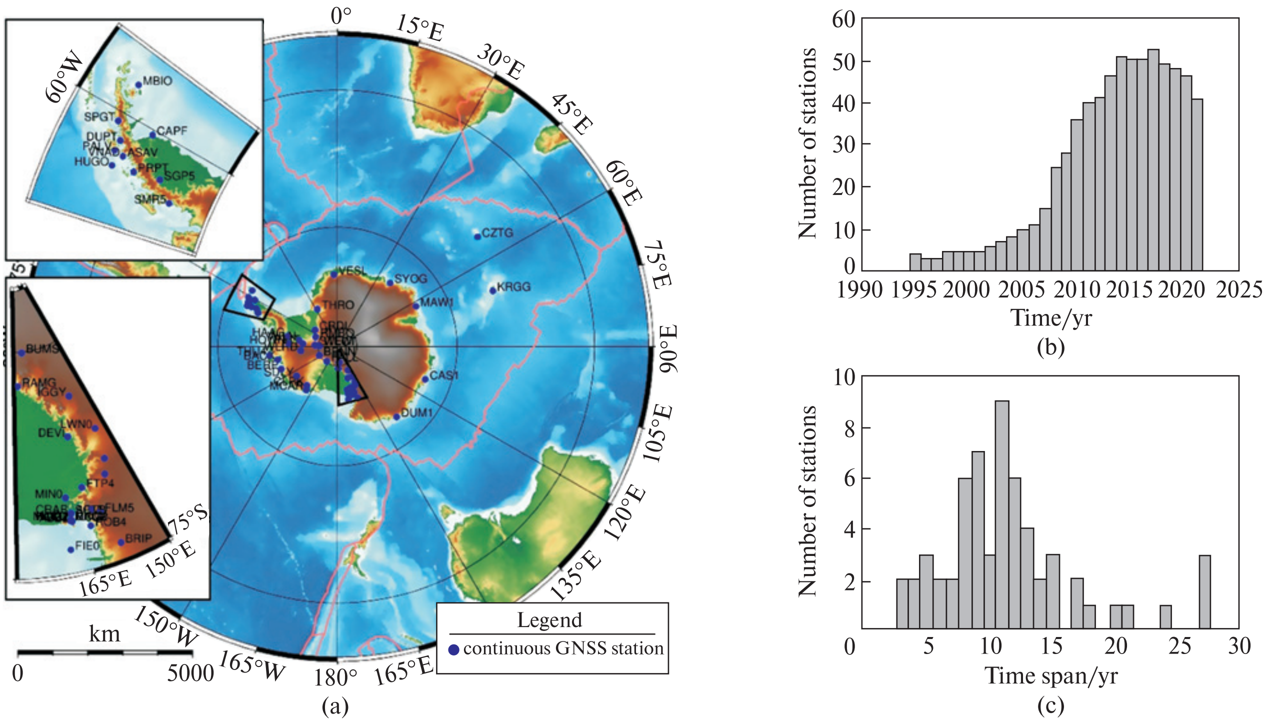

Figure 2. Scheme of the location of continuous GNSS stations of the Antarctic tectonic plate used in the study (a) and their characteristics in term of (b) station availability and (c) station time span. (The figures were compiled using plate boundaries of Bird (2003) and GNSS stations characteristics diagrams of Savchyn et al. (2023))

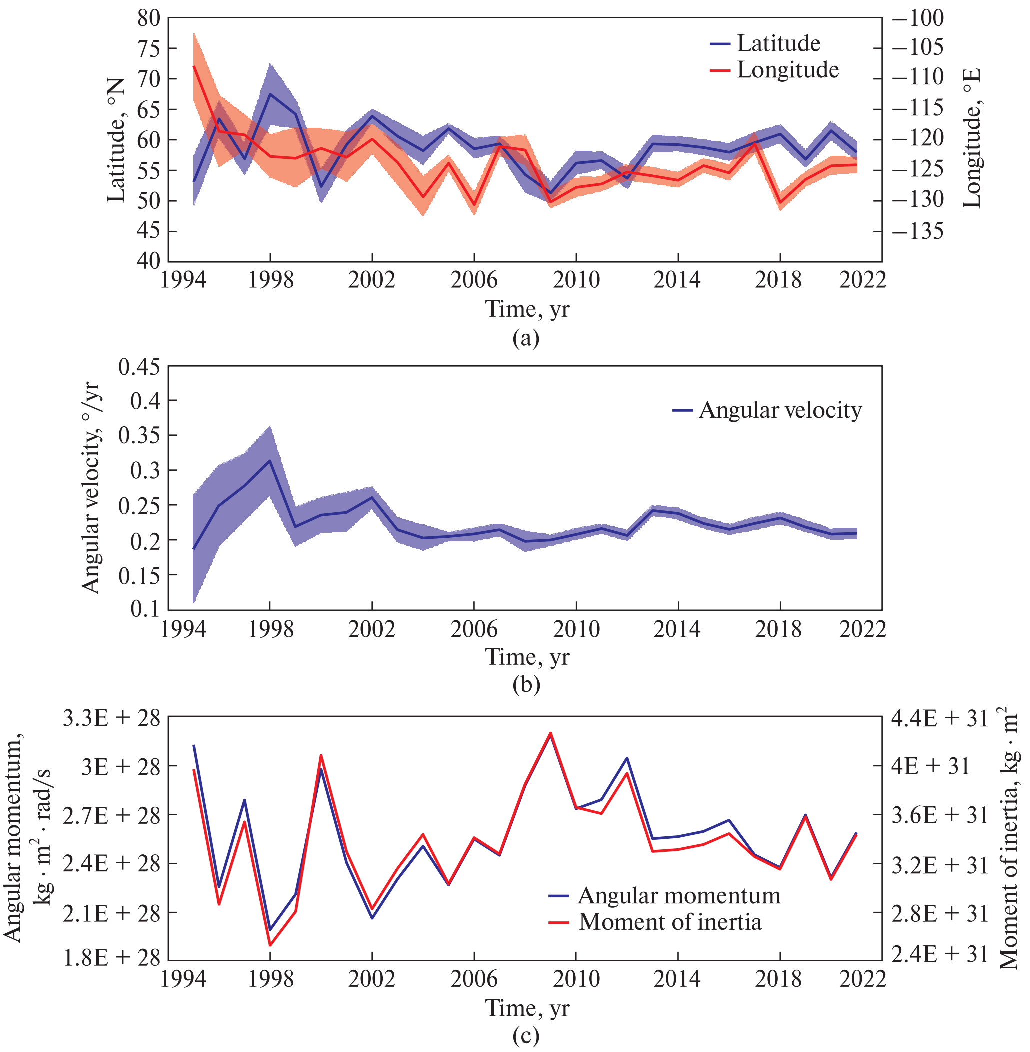

Figure 3. Values of annual parameters of the Antarctic Plate in 1995–2021 in terms of (a) pole coordinates, (b) angular velocity, (c) moment of inertia and angular momentum

impact on other parameters under research. Another important point is that the accuracy of the determination is much higher than the magnitude of the values. This confirms that the rotation poles, the moment of inertia and angular momentum of the Antarctic Plate are dynamic parameters. However, additional calculations and in-depth comprehensive analysis are required to determine the causes of such dynamics.

4 Discussion

It is known that the unevenness of the Earth's rotation can be periodic (or quasi-periodic), age-related, and irregular. The reason for periodic changes in the Earth's rotation velocity is the Earth's tides caused by the gravity of the Sun and Moon. According to Wu et al. (2012), the age-related slowdown of the Earth's rotation velocity (due to tidal friction in the Earth's body and oceans) is the cause of tectonic plate movement. Sottili et al. (2015) note that changes in the LOD (Length of Day) lead to horizontal shear stresses, which, in interaction with the uneven rotational motion of the Earth, are the dominant factor influencing the Earth's geodynamic processes and their manifestation in seismic and volcanic activity.

 ISSN 1727-7485. Ukrainian Antarctic Journal, 21(1), 2023, https://doi.org/10.33275/1727-7485.1.2023.704

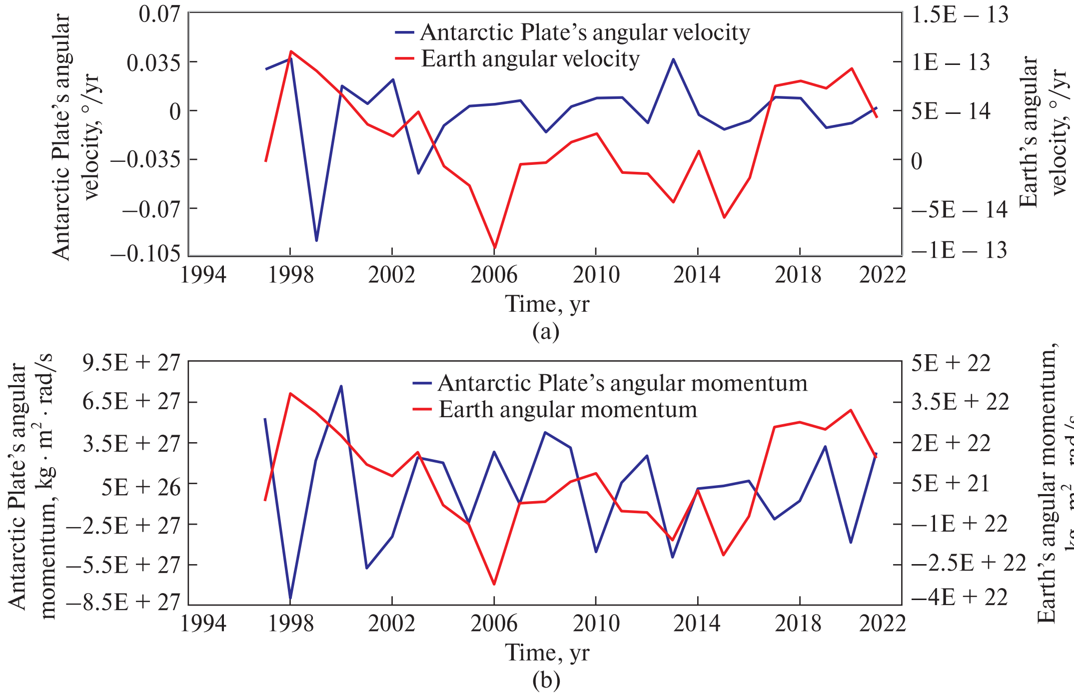

Figure 4. Changes in values of annual parameters of the Antarctic Plate and Earth for 1995–2021 in terms of (a) Antarctic Plate's angular velocity and Earth's rotation velocity and (b) Antarctic Plate's angular momentum and Earth's conditional angular momentum

In other words, the unevenness of the Earth's rotation leads to redistribution of the angular momentum between the Earth's crust, hydrosphere, and atmosphere, the appearance of force stresses between the Earth's core and mantle, and violation of isostatic and postglacial equilibrium. It can also trigger the release of stored energy in the Earth's crust and the excitation of seismic and volcanic activity. Therefore, in the framework of the analysis and discussion, it was decided to establish a possible relationship between the dynamics of changes in the rotation poles of the Antarctic Plate and the unevenness of the Earth's rotation.

The input data for the calculation of the Earth's rotation were the values of the change in LOD, freely available on the website of the International Earth Rotation Service (International Earth Rotation and Reference Systems Service, https://www.iers.org). The change in LOD values is the difference in the values of the periods $P_{Ed} - P_{Ad}$, where P_{Ed} is the period of the Earth Day, and P_{Ad} is the period of the Astronomical Day (86400 s). Based on the values of the change in LOD, the annual angular velocity of the Earth's rotation was determined:

$$\omega_{\otimes} = \Omega_N \cdot \left|1 - \frac{LOD}{T}\right|, \quad (4)$$

where Ω_N is the nominal rotation velocity of the Earth (corresponding to the rotation velocity of the average epoch of 1820), which is equal to $72921151.467064 \cdot 10^{-12}$ rad/s, T is the duration of an average Solar Day of 86 400 sec TAI. To obtain the annual angular velocity of the Earth's rotation, we used the average annual LOD values.

According to the law of conservation of angular momentum, the angular momentum of the Earth is a constant value. However, the position of the Earth's rotation axis and its rotation velocity are constantly changing. Therefore, it is obvious that changes in these parameters compensate for each other to keep the Earth's angular momentum constant. Additionally, this change is compensated by the movements of the core, mantle, tectonic plates, ocean, atmosphere, and many other factors.

Since the Earth's angular momentum is a constant value, it was decided to operate with the conditional angular momentum of the Earth in this study, which takes into account only the change in the Earth's rotation velocity:

$$L_E = I_E \cdot \omega_{\otimes}, \tag{5}$$

where I_E is the Earth's moment of inertia ($9.723 \times \times 10^{37}$ kg · m^2).

To establish a possible relationship between the dynamics of changes in the rotation poles of the Antarctic Plate and the Earth's rotational irregularity, Figure 4 shows changes in their annual values for 1995—2021.

Analyzing the data presented on Figure 4, it can be noted that there is no clear relationship between the determined parameters. Obviously, the correlation between the rotation poles of the Antarctic Plate and the Earth rotation cannot be high, since the change in the Earth's angular momentum depends not only on the Antarctic Plate but also on many other parameters.

The change in the angular velocity of the Antarctic Plate and the change in the Earth's rotation velocity (see Figure 4a) are asynchronous (in 2000, 2002, 2003, 2004, 2005, 2006, 2008, 2011, 2012, 2013, 2014, 2019, and 2021) or synchronous (in 1998, 1999, 2001, 2007, 2009, 2010, 2015, 2016, 2017, 2018, and 2020). The change in the angular momentum of the Antarctic Plate and the change in the conditional angular momentum of the Earth (see Figure 4b) are asynchronous (in 1998, 1999, 2000, 2002, 2006, 2007, 2009, 2010, 2011, 2012, 2015, 2019, 2020, and 2021) or synchronous (in 2001, 2003, 2004, 2005, 2008, 2013, 2014, 2016, 2017, and 2018).

That is, in most cases (54%), an increase in the Earth's rotation velocity leads to a decrease in the angular velocity of the Antarctic Plate, and in most cases (58%), an increase in the conditional angular momentum of the Earth leads to a decrease in the angular momentum of the Antarctic Plate. Such processes are evidence that Antarctic Plate's dynamics partially compensate for the unevenness of the Earth's rotation to keep the Earth's angular momentum constant. However, it is obvious that the dynamics of the Antarctic Plate are not the determining factor in compensating for these processes. Continuation of such studies on other tectonic plates may allow us to better understand these processes and establish certain functional dependencies that will make it possible to predict them. For example, to predict crustal movements based on annual changes in the Earth's rotation velocity.

5 Conclusions

An algorithm for determining the moment of inertia and angular momentum of the tectonic plate was developed based on the processing of time series of daily solutions of continuous GNSS stations. The algorithm was tested to determine the annual values of the moment of inertia and angular momentum of the Antarctic tectonic plate for 1995—2021.

It is confirmed that the rotation poles and the moment of inertia and angular momentum of the Antarctic Plate are dynamic parameters. However, additional calculations and in-depth, comprehensive analysis are required to determine the causes of such dynamics.

As a result of comparing the dynamics of changes in the rotation poles of the Antarctic plate and the unevenness of the Earth's rotation, it was found that the dynamics of the Antarctic plate partially compensate for the unevenness of the Earth's rotation to keep the angular momentum of the Earth constant.

The presented algorithm and the results obtained can be used to develop new and refine existing models of tectonic plate movements and coordinate systems and to predict the movements of the Earth's crust.

*Data availability***.** The raw data supporting the conclusion of this article are available upon request.

Author contributions. Idea, conceptualization: I.S., K.T. Data collection and preparation: I.S. Formal analysis: I.S. Research: I.S, K.T. Visualization: I.S. Summary: I.S. Initial draft: I.S, K.T. Writing, reviewing, editing: I.S, K.T.

Acknowledgments. The authors are grateful to the reviewers and editors for their constructive and valuable comments that significantly improved the manuscript.

Funding. The study was done with the financial support of the State Institution National Antarctic Scientific Center of the Ministry of Education and Science of Ukraine as a part of the Scientific and Research Projects No.: H/6-2019, No.: H/18-2020 and No.: H/22-2021.

Conflict of Interest. The authors declare no conflict of interest.

References

Altamimi, Z., Métivier, L., Rebischung, P., Rouby, H., & Collilieux, X. (2017). ITRF2014 plate motion model. *Geophysical Journal International*, *209*(3), 1906–1912. https://doi.org/10.1093/gji/ggx136

Altamimi, Z., Sillard, P., & Boucher, C. (2002). ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications. *Journal of Geophysical Research: Solid Earth, 107*(B10), ETG 2–1–ETG 2–19. https://doi.org/10.1029/2001jb000561

Argus, D. F., & Gordon, R. G. (1991). No-net-rotation model of current plate velocities incorporating plate motion model NUVEL-1. *Geophysical Research Letters, 18*(11), 2039–2042. https://doi.org/10.1029/91gl01532

Argus, D. F., Gordon, R. G., & DeMets, C. (2011). Geologically current motion of 56 plates relative to the no-net-rotation reference frame. *Geochemistry, Geophysics, Geosystems*, *12*(11). https://doi.org/10.1029/2011gc003751

Atanasova-Zlatareva, M. (2014). Research of the horizontal crustal motions, based on GPS Data for the territory of Bulgaria and the Balkans (7093). In *Engaging the Challenges – Enhancing the Relevance XXV FIG Congress 2014 in Kuala Lumpur, Malaysia 16–21 June 2014* (pp. 1–11). FIGNET.

Bird, P. (2003). An updated digital model of plate boundaries. *Geochemistry, Geophysics, Geosystems, 4*(3). https://doi.org/10.1029/2001gc000252

Blewitt, G., Hammond, W. C., & Kreemer, C. (2018). Harnessing the GPS data explosion for interdisciplinary science. *Eos, 99*. https://doi.org/10.1029/2018EO104623

Brown, W. K., & Wohletz, K. H. (2007). *SFT and the Earth's Tectonic Plates*. Los Alamos National Laboratory. https://www.lanl.gov/orgs/ees/geodynamics/Wohletz/SFT-Tectonics.htm

Calais, E., Han, J. Y., DeMets, C., & Nocquet, J. M. (2006). Deformation of the North American plate interior from a decade of continuous GPS measurements. *Journal of Geophysical Research: Solid Earth, 111*(B6). https://doi.org/10.1029/2005jb004253

Dimitrov, N., & Nakov, R. (2022). GPS Results from long time monitoring of geodynamic processes in South-Western Bulgaria. *Applied Sciences*, *12*(5), 2682. https://doi.org/10. 3390/app12052682

Drewes, H. (2009). The actual plate kinematic and crustal deformation model APKIM2005 as basis for a non-rotating ITRF. In H. Drewes (Ed.), *Geodetic Reference Frames. International Association of Geodesy Symposia* (Vol. 134, pp. 95–99). Springer Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-00860-3_15

Euler, L. (1776). Formulae generales pro translation equacunque corporum rigidorum (General formulas for the translation of arbitrary rigid bodies). *Novi Commentarii academia escientiarum Petropolitanae*, 20, 189–207 (E478). (In Latin)

Jagoda, M. (2021). Determination of motion parameters of selected major tectonic plates based on GNSS station positions and velocities in the ITRF2014. *Sensors, 21*(16), 5342. https://doi.org/10.3390/s21165342

Laske, G., Masters., G., Ma, Z., & Pasyanos, M. (2013). Update on CRUST1.0 - A 1-degree Global Model of Earth's Crust. *Geophysical Research Abstracts*, *15*, Abstract EGU2013-2658.

Li, Y., Liu, M., Li, Y., & Chen, L. (2019). Active crustal deformation in southeastern Tibetan Plateau: The kinematics and dynamics. *Earth and Planetary Science Letters, 523,* 115708. https://doi.org/10.1016/j.epsl.2019.07.010

Lobkovsky, L. I., & Kerchman, V. I. (1991). A two-level concept of plate tectonics: application to geodynamics. *Tectonophysics*, *199* (2–4), 343–374. https://doi.org/10.1016/0040-1951(91)90178-U

Marchenko, O. M., Tretyak, K. R., Kylchitskiy, A. Ya., Golubinka, Yu. I., Marchenko, D. O., & Tretyak, N. P. (2012). Doslidzhennya hravitatsiynoho polya, topohrafiyi okeanu ta rukhiv zemnoyi kory v rehioni Antarktyky [*Investigation of the gravitational field, ocean topography and crustal movements in the Antarctic region*]. Lviv Polytechnic Publishing House. (In Ukrainian)

Saria, E., Calais, E., Stamps, D. S., Delvaux, D., & Hartnady, C. J. H. (2014). Present-day kinematics of the East African Rift. *Journal of Geophysical Research: Solid Earth*, *119*(4), 3584–3600. https://doi.org/10.1002/2013JB010901

Savchyn, I. (2022a). Establishing the correlation between changes of absolute rotation poles of major tectonic plates based on continuous GNSS stations data. *Acta Geodynamica et Geomaterialia*, *19*(2), 167–176. https://doi.org/10.13168/AGG.2022.0006

Savchyn, I. (2022b). Determination of the recent rotation poles of the main tectonic plates on the base of GNSS data. *Geodynamics, 2*(33). 17–27. https://doi.org/10.23939/jgd2022.02.017

Savchyn, I. (2022c). Migration of average annual rotation poles of Antarctic Plate during 1995–2021 by GNSS data. In *16th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment* (Vol. 2022, pp. 1–5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.2022580045

Savchyn, I. (2023). Analysis of recent African tectonic plate system kinematics based on GNSS data. *Acta Geodynamica* *et Geomaterialia*, *20*(2), 19–28. https://doi.org/10.13168/AGG.2023.0003

Savchyn, I., Brusak, I., & Tretyak, K. (2023). Analysis of recent Antarctic plate kinematics based on GNSS data. *Geodesy and Geodynamics*, *14*(2), 99–110. https://doi.org/10.1016/j.geog.2022.08.004

Savchyn, I., Tretyak, K., Marusazh, K., & Korliatovych, T. (2021a). Processing and analysis of measurement results of the Ukrainian GNSS station ASAV (Argentina Islands, West Antarctica). In *International Conference of Young Professionals «GeoTerrace-2021»* (Vol. 2021, pp. 1–5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.20215K3032

Savchyn, I., Otruba, Y., & Tretyak, K. (2021b). The first Ukrainian permanent GNSS station in Antarctica: processing and analysis of observation data. *Ukrainian Antarctic Journal*, 2, 3–11. https://doi.org/10.33275/1727-7485.2.2021.674

Sella, G. F., Dixon, T. H., & Mao, A. (2002). REVEL: A model for Recent plate velocities from space geodesy. *Journal of Geophysical Research: Solid Earth, 107*(B4), ETG 11–1–ETG 11–30. https://doi.org/10.1029/2000jb000033

Simmons, N. A, Myers, S. C. Johannesson, G., & Matzel, E. (2012). LLNL-G3Dv3: Global P wave tomography model for improved regional and teleseismic travel time prediction. *Journal of Geophysical Research: Solid Earth*, *117*(B10). http://dx.doi.org/10.1029/2012JB009525

Sottili, G., Palladino, D. M., Cuffaro, M., & Doglioni, C. (2015). Earth's rotation variability triggers explosive eruptions in subduction zones. *Earth, Planets and Space, 67*(1), 208. https://doi.org/10.1186/s40623-015-0375-z

Tretyak, K., Al-Alusi, F. K. F., & Babiy, L. (2018). Investigation of the interrelationship between changes and redistribution of angular momentum of the Earth, the Antarctic tectonic plate, the atmosphere, and the ocean. *Geodynamics*, *1*(24), 5–26. https://doi.org/10.23939/jgd2018.01.005

Vassileva, K., & Atanasova, M. (2014). Study of plate tectonic transition boundaries in Bulgaria from GPS. In *Tenth Anniversary Scientific Conference with International Participation SPACE, ECOLOGY, SAFETY 12–14 November 2014, Sofia, Bulgaria* (pp. 356–362). Space Research and Technology Institute – Bulgarian Academy of Sciences.

Vassileva, K., & Atanasova, M. (2016). Earth movements on the territory of Bulgaria and Northern Greece from GPS observations. *Comptes rendus de l'Académie bulgare des Sciences, 69*(11).

Wu, X., Ray, J., & van Dam, T. (2012). Geocenter motion and its geodetic and geophysical implications. *Journal of Geodynamics, 58,* 44–61. https://doi.org/10.1016/j.jog.2012.01.007

Xiang, Y., Yue, J., Liu, G., & Chen, Y. (2022). Characterizing the spatial patterns of vertical crustal deformations over the South American continent based on GNSS imaging. *Pure and Applied Geophysics*, *179*(10), 3569–3587. https://doi.org/10.1007/s00024-022-03144-3

Zhou, Y., He, J., Oimahmadov, I., Gadoev, M., Pan, Z., Wang, W., Abdulov, S., & Rajabov, N. (2016). Present-day crustal motion around the Pamir Plateau from GPS measurements. *Gondwana Research, 35,* 144–154. https://doi.org/10.1016/j.gr.2016.03.011

Received: 17 May 2023
Accepted: 20 July 2023

І. Савчин*, **К. Третяк**

Національний університет «Львівська політехніка»,
м. Львів, 79013, Україна

*** Автор для кореспонденції**: ih.savchyn@gmail.com

Визначення моменту інерції та моменту імпульсу тектонічних плит у випадку Антарктичної плити

Основною метою цієї роботи є розроблення та апробація алгоритму визначення моменту інерції та моменту імпульсу тектонічної плити на основі опрацювання часових рядів щоденних розв'язків перманентних ГНСС-станцій. Структурно запропонований алгоритм складається із чотирьох послідовних етапів: переформатування даних у внутрішній формат; поділ тектонічної плити на комірки та визначення маси цих комірок; визначення ротаційних параметрів та відстаней від комірок до полюса обертання; визначення моменту інерції та моменту імпульсу. Алгоритм передбачає використання наявних у вільному доступі часових рядів щоденних розв'язків перманентних ГНСС-станцій або будь-яких інших даних, підготовлених у аналогічному форматі. Алгоритм апробовано для визначення моменту інерції та моменту імпульсу Антарктичної тектонічної плити на основі опрацювання часових рядів щоденних розв'язків 60-ти перманентних ГНСС-станцій для періоду 1995–2021 роки. На основі опрацювання отриманих результатів підтверджено, що ротаційні параметри, а також момент імпульсу та момент інерції Антарктичної плити є динамічними параметрами. Проте, для встановлення причин такої динаміки потрібно провести додаткові обчислення та глибинний комплексний аналіз. У результаті порівняння динаміки змін ротаційних параметрів Антарктичної плити та нерівномірності обертання Землі встановлено, що в більшості випадків (54%) збільшення швидкості обертання Землі призводить до зменшення кутової швидкості Антарктичної плити, а в більшості випадків (58%) збільшення умовного моменту імпульсу Землі призводить до зменшення моменту імпульсу Антарктичної плити, тобто динаміка Антарктичної плити частково компенсує нерівномірність обертання Землі для збереження моменту імпульсу Землі сталим. Проте очевидно, що динаміка Антарктичної плити не є визначальним фактором компенсації цих процесів. Представлений алгоритм та отримані результати можуть бути використані для розроблення нових та уточнення існуючих моделей рухів тектонічних плит та систем координат, а також для прогнозування рухів земної кори.

Ключові слова: ГНСС-дані, математичне моделювання, полюси обертання, рухи земної кори