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# ANALYSIS OF VERTICAL MOVEMENTS OF THE PERMANENT GNSS STATION POLV ON THE BASE OF SATELLITE DATA AND LEVELING

The purpose of this work is to analyze the results of the study of the dynamics of vertical movements of the permanent station of the GNSS positioning system "Poltava" (identifier POLV). Method. A geodynamic test site was set up on the territory of the Poltava Gravimetric Observatory. It includes rappers with known stability indicators laid at different depths. The exact level of H–05 is set on the A1 standard, which is characterized by high stability over 30 years of observations. The GNSS station, the vertical movements of which were studied, is installed on a specially built pedestal on the inner capital wall of the laboratory building of the Poltava Gravimetric Observatory of the S. I. Subbotin Institute of Geophysics of the National Academy of Sciences of Ukraine. The movement dynamics of the base station was monitored by marks placed on the edges of the western and eastern sides of the laboratory building. To evaluate and compare the obtained results, satellite data were processed by the method of approximation of polynomial smoothing of the third degree. According to the results of periodic geometric leveling, it was established that for the period 2004–2019, the slow vertical movements of the stamps were 1.03–1.11 mm with an average annual rate of rise of 0.065–0.07 mm/year. Seasonal vertical movements of the permanent GNSS station POLV are within 2 mm/year, and in the first half of the year, there is a rise of the point and a decline was in the second half of the year. Selected components that can affect the vertical movements of a GNSS station installed on an engineering structure. A comparison of ground and satellite observations results was made for the periods of 2004–2005 and 2018–2019. Based on the observations and modeling, the component of vertical oscillations of the receiving antenna obtained in the period of 2004–2005 by both ground and satellite methods did not exceed 2 mm; in the period of 2018–2019, the analysis of satellite data showed an increase in fluctuations up to 7 mm. This can be explained by a large spread of satellite measurements. Scientific novelty and practical significance lie in the detected stability of the amplitude of vertical movements of the GNSS station, which was confirmed by the ground method of geometric leveling and the analysis of the time series of satellite observations. The conducted studies confirm the influence of various factors on the stability of receiving antennas.

*Key words:* global navigation satellite systems (GNSS), permanently operating (permanent) stations, receiving antennas, vertical displacements, geometric leveling, satellite observation data.

## Introduction

Today in Ukraine, there is a growing need to deploy a network of permanent reference GNSS stations that accumulate data with the necessary accuracy characteristics of position, navigation, and timing (PNT). The high-precision coordinate-time provision of a significant share of geodetic, land management, and other works with the use of GNSS technologies significantly increases the efficiency and pace of their implementation. The presence of GNSS stations network in any region allows provision of centralized information support for the geodetic works of users throughout the region. In the coverage area of the network, users get the opportunity to achieve centimeter accuracy when using one geodetic receiver of satellite navigation signals.

The eastern region of Ukraine is particularly poorly equipped with points. Existing base stations require high accuracy characteristics. It is necessary to constantly check the offsets of receiving antennas, and identify factors that can affect the stability of permanent network stations, and therefore, the accuracy of determining their location. Receiving antennas of GPS equipment are located on structures, buildings, special pedestals, and foundations, which are often located in the zone of significant soil deformations under the influence of hydrothermal factors.

This can distort the results of monitoring the earth's surface and call into question the reliability of their interpretation [Pavlyk, et al., 2020]. Such monitoring is effective when both ground geodetic methods and satellite observations are used for verification. The GNSS station POLV, which is included in the IGS and EPN networks, was selected for the study of vertical displacements.

### The purpose

The purpose of this work is to analyze the results of the study of the dynamics of vertical movements of the permanent station of the GNSS positioning system «Poltava» (identifier POLV).

### Method

A geodynamic test site was set up on the territory of the Poltava Gravimetric Observatory. It includes rappers with known stability indicators laid at different depths. The exact level of H–05 is set on the A1 standard, which is characterized by high stability over 30 years of observations. The GNSS station, the vertical movements of which were studied, is installed on a specially built pedestal on the inner capital wall of the laboratory building of the Poltava Gravimetric Observatory of the S. I. Subbotin Institute of Geophysics of the National Academy of Sciences of Ukraine. The dynamics of the movement of the base station were monitored by marks placed on the edges of the western and eastern sides of the laboratory building. To evaluate and compare the obtained results, satellite data was processed by the method of approximation of polynomial smoothing of the third degree.

To date, more than 410 active GNSS monitoring stations have been installed in Ukraine, owned by various operators. The most famous network is UPM GNSS (UAPOS – Ukrainian network of permanent observation stations of global navigation satellite systems). 9 stations are part of the European Permanent Network (EPN) and 7 – to the International GNSS Service (IGS) of the International GNSS Service [GNSS – hrupa HAO NAN Ukrainy]. It is known that the Ukrainian network of permanent GNSS stations was created to improve the accuracy of geodetic measurements in Ukraine and link the coordinate system to the International Terrestrial Reference System ITRF. UPM GNSS is designed to solve scientific and technical problems with the highest accuracy, to provide users working in the field of geodesy and land management, the ability to practically obtain the coordinates of any accessible point on the earth's surface or in the surrounding space with sufficient accuracy (in centimeters) and efficiency (in seconds/minutes). UPM GNSS currently includes the following: permanent observation stations of global navigation satellite systems, which continuously conduct integrated satellite, geodetic, gravimetric, and geophysical observations; periodic observation stations of global navigation satellite systems, which conduct complex satellite, geodetic, gravimetric, and geophysical observations at least once every five years; information processing centers (Center for Geodetic Research of the Research Institute of Geodesy and Cartography, the Main Astronomical Observatory of the National Academy of Sciences and the Center for Navigational Field Control of the SCA).

Other networks have also been developed in Ukraine: GAO NASU (Main Astronomical Observatory of the National Academy of Sciences of Ukraine), NDIGK (Research Institute of Geodesy and Cartography), SCNSU (Space Navigation and Time Support System of Ukraine), Geoterrace (GNSS network of the Institute of Geodesy of Lviv Polytechnic National University), ZAKPOS (Transcarpathian Position Determination System – a network of reference GNSS stations), TNT – TPI GNSS Network (network of active reference stations of the company “TNT TPI”), System.NET (GNSS network PJSC “System Solutions”), NGS NET (regional system of high-precision geodetic measurements in the Kharkiv region).

The stations are equipped with equipment from Leica, GPS COM, Trimble, and TOPCON [GNSS-hrupa HAO NAN Ukrainy]. Antennas allow receiving signals from GPS satellites NAVSTAR (USA), GLONASS (Russia), Galileo (EU), and BeiDou (China).

The key instrument in supporting the International Terrestrial Reference System is the IGS permanent station network and the European Terrestrial Reference System 1989. It is the EUREF – EPN permanent station network. Currently, about 200 organizations are collecting GNSS data from base stations around the world. They are merged into IGS (International GNSS Service).

The IGS data processing and analysis centers include Natural Resources of Canada EMR (Canada), Wuhan University WHU (China), Geodetic

Observatory Safe GOP-RIGTC (Czech Republic), Space Agency CNES GRG (France), European Space Agency ESA/ESOC (Germany), GeoForschungsZentrum GFZ (Germany), European Center for Determination of Orbits CODE (Switzerland), JPL Jet Propulsion Laboratory (USA), Massachusetts Institute of Technology MIT (USA), National Geodetic Survey NGS (USA), Scripps Institute of Oceanography SIO (USA), American Marine Observatory USNO (USA). The basis of IGS is a global network of more than 400 permanent stations that track GPS, GLONASS, Galileo, and BeiDou signals in combination with space (WAAS, EGNOS, MSAS, etc.), ground and autonomous onboard functional additions [Nesterenko, 2021].

The European Permanent Network (EPN) is a voluntary association of over 100 universities, research institutes, and commercial institutions in over 30 European countries. The European network of permanent stations includes over 300 permanent GNSS stations, data centers, analytical centers (analyzing GNCC data), coordinators (generating EPN), Central Office (responsible for daily monitoring and management of EPN).

The network operates under the auspices of the IAG (International Association of Geodesy) subcommittee of the EUREF Regional Reference Commission for Europe [EUREF Permanent GNSS Network].

The study of the dynamics of changes in the coordinates of permanent satellite stations is of particular importance both from the point of view of improving the implementation of the Earth’s coordinate system and in connection with the need to study the physical phenomena that cause these changes [Tretyak, et al., 2012; Yankiv-Vitkovska, 2011; Savchuk, et al., 2019]. Scientists are engaged in the development of methods for determining the movements of base stations, forecasting and constructing models of movements and deformations, as well as identification factors affecting the dynamics of base stations [Lompas, et al., 2016; Pavlyk, et al., 2020; Dong, et al., 2002; Gulal, et al., 2013; Isawi, et al., 2022]. The task of the authors of the article is to determine the amplitudes of vertical movements of the GNSS station POLV.

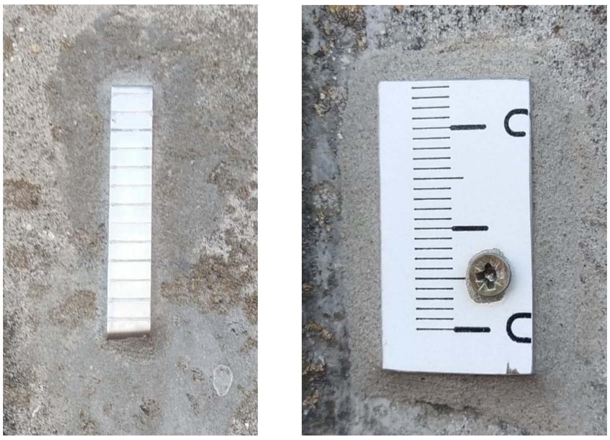
**The results**

The permanent station of the GNSS positioning system “Poltava” (identifier POLV) was organized in 2001 on the territory of the Poltava Gravimetric Observatory of the S. I. Subotin Institute of Geophysics of the National Academy of Sciences of Ukraine. After the start of regular observations, the POLV station was included in the IGS (June 2001) and EPN (September 2001) networks. The receiving antenna is installed on a specially built pedestal, which is located on the inner capital wall of the laboratory building of the observatory (Fig. 1). The building was built more than 100 years ago; the height of the receiving antenna above the ground is 10.6 m.

The method of repeated geometric leveling was used as the main method of ground geodetic observations [Lyon, et al., 2018]. On the territory of the observatory, a geodynamic test site was set up for the purpose of studying the impact of exogenous factors of meteorological origin on the dynamics of the earth's surface, benchmarks of different depths with known stability indicators were laid. At a distance of 75 m from the station, there is a benchmark A1 with a depth of 6 m, which is characterized by high stability during all 30 years of observations. There are no slow and seasonal movements in the dynamics of this sign. It was this benchmark that was chosen as the starting point when determining the characteristics of the possible vertical dynamics of the receiving antenna of the GNSS station.

*Fig. 1. Place of the installation of GNSS station “Poltava” (POLV) Source: [archive photo of the authors]*

In 2004–2005, the first observations were made of local vertical movements of the station under the influence of variations in hydrothermal factors. For this purpose, two stainless steel marks with applied divisions were placed on the edge of the western and eastern sides of the observatory building, the vertical position of which was constantly monitored by the method of repeated geometric leveling (Fig. 2, *a*).



*a* *b*

*Fig. 2. Marks placed on the wall of the observatory building for observations of vertical movements of the station: a – in 2004–2005; b – in 2018–2019. Source: [archive photo of the authors]*

Based on the observations and simulations, the seasonal component of possible vertical oscillations of the receiving antenna was obtained, the value of which did not exceed 2 mm. The short period of observation did not allow for determining the presence or absence of slow vertical movements of the GNSS station under the influence of external factors. Therefore, in 2018, monitoring of the stability of the station was continued in order to determine the speed of its slow local vertical movements and confirm the previously obtained seasonal fluctuations.

The leveling marks, which were placed in 2004 on the building of the observatory and were used to determine the dynamics, were not sufficiently contrasting, which created certain difficulties during observations. In 2018, another pair of marks was installed on the edges of the building, which is located approximately 1 m lower than the previous one (Fig. 2, *b*). The relative height of the marks has changed due to a change in the configuration of the height network. Now, the leveling of new marks is carried out from two stations, and not from one, as it was in 2004–2005. The increase in the number of leveling stations in 2018–2019 did not increase the error in determining the height position of the marks, but on the contrary, reduced it. This was due to a significant reduction in the error of aiming at the contrasting strokes of the new marks compared to the old ones.

Since the total number of observations for two years is relatively small and they were carried out asymmetrically during the year, for a more reliable determination of the quantitative characteristics of their vertical movements, their average movement for two years of determinations was obtained. Fig. 3 shows the vertical movements of the W and E marks, which are located on the west and east sides of the observatory building, respectively.

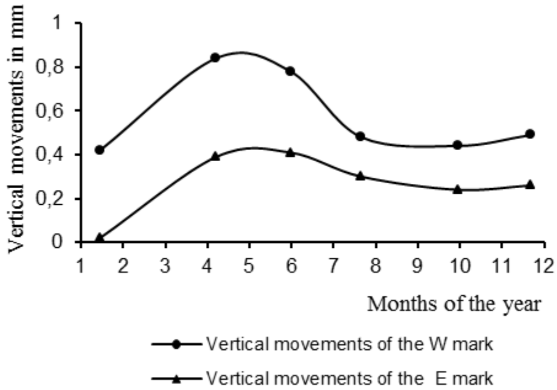



*Fig. 3. Average seasonal vertical movement of W and E marks for 2018–2019 relative to benchmark A1*

Both marks carry out a parallel seasonal vertical movement, which is well correlated with the level of groundwater and seasonal variations of soil moisture, which is confirmed by Fig. 4.

The soil level was determined in the basement of the observatory building, and the soil moisture near the location of benchmark A1 at the moments of observation of the level marks W and E.

Let us consider the individual components that determine the vertical fluctuations of marks. The ground and underground parts of a building experience seasonal linear temperature expansions. This includes the marks above the ground surface ($h_{0\text{-}1.55}$) and the soil up to 15 meters below the surface ($h_{0\text{-}15}$). Additionally, there are temperature deformations of the initial benchmark A1 ($h_{0.5\text{-}6(A1)}$) and the soil below it to a depth of 15 meters ($h_{6\text{-}15(A1)}$). The foundation of a building may also experience vertical movements due to periodic fluctuations of soil moisture ($h_{\phi}$), as evidenced by Fig. 4.

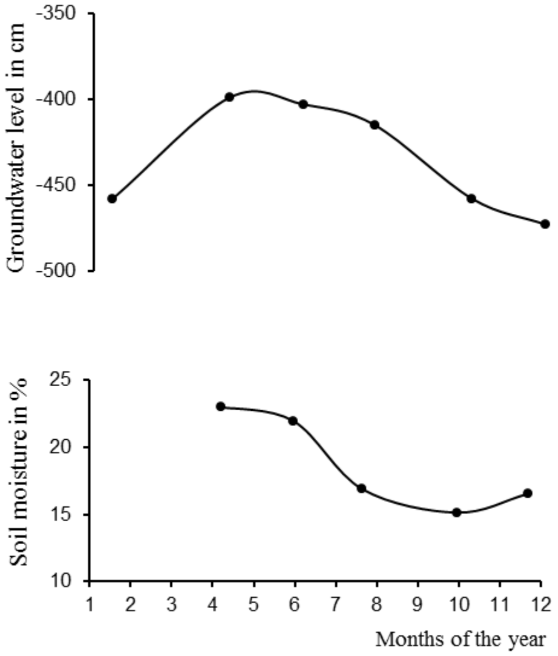



*Fig. 4. Average fluctuations in the level of groundwater and soil moisture in 2018–2019 at the Poltava GP*

Then, the average vertical movement of the level marks W and E $h_M$ at any moment in time can be represented as follows:

$$h_M = h_{0-1,55} + h_{0-15} + h_{ф} - h_{0,5-6(A1)} - h_{6-15(A1)} . \quad (1)$$

An empirical formula was previously obtained [Pavlyk, 2013], which allows calculating the soil temperature $T_z$ at the GP in Poltava at any moment in time at any depth z from the surface of the earth:

$$T_z = T_0 + 15,0e^{-0.380 z} \cos(0^0,986t - 194^0,0 - 20,6^0 z) , \quad (2)$$

where $T_0$ is the average annual temperature value; t – days of the year starting from January 1.

Formula (2) allows us to calculate all terms of formula (1) except $h_ф$. In fig. 5 it is showed the seasonal fluctuations of the average vertical position of the level marks with the removed deformations of the original benchmark and the soil under its monolith and the possible vertical movement of the foundation on which the GNSS station is placed according to formula (1).

The depth of the foundation of the observatory building is unknown, as it was built more than a hundred years ago. Seasonal vertical movements of soil layers in the range from the surface of the earth to a depth of 2.5 m have been determined for a long time at the Poltava State Hydroelectric Plant. The best probable vertical movement of the foundation of the building with a GNSS receiver (Fig. 5) describes the soil layer at a depth of 0.9–1.2 m from the surface. Fig. 6 shows the average seasonal trend of these two values for 2018–2019.

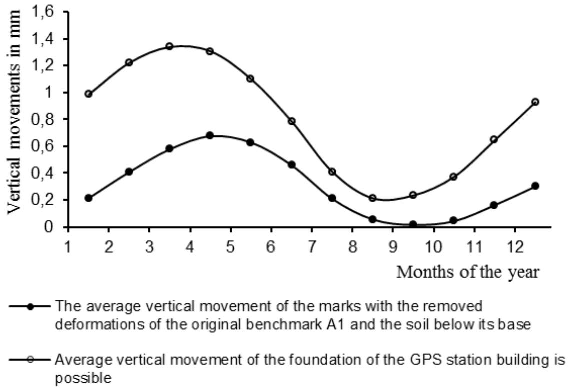



*Fig. 5. Average seasonal vertical movement of the foundation of the GNSS station building for 2018–2019*

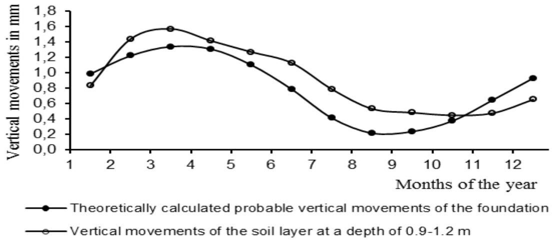



*Fig. 6. Average seasonal vertical movements of the foundation of the building where the GNSS receiver is located and the soil layer at a depth of 0.9–1.2 m from the ground surface for 2018–2019*

The simulated seasonal vertical movements of the receiving antenna of the GNSS station $h_{GPS}$ at any time $t_i$ can be obtained from the following simple expression:

$$(h_{GPS})_i = (h_M)_i - (h_{0-1,55})_i - h_{(0,5-6)A1} - h_{(6-15)A1} + (h_{\text{буд.}})_i + (h_{\text{пост.}})_i , \quad (3)$$

where $(h_M)_i$ – the vertical movements of the GNSS station to the average height of the W and E marks at the moment of time *ti*, which are obtained as a result of their repeated leveling;$(h_{0\text{-}1,55})_i$ – vertical movements of the outer wall of the building from the ground surface to the average position of the leveling marks at a height of 1.55 m; $(h_{\text{буд}})_i$ – vertical movements of the GNSS station due to temperature deformations of the capital wall inside the building on which the antenna pedestal is installed at time $t_i$; $(h_{\text{пост}})_I$ – vertical movements of the GNSS station due to temperature deformations of the antenna pedestal at time $t_i$:

$$(h_{\text{буд.}})_i = \alpha L_{\text{буд.}}(T_{\text{буд.}})_i\,, \tag{4}$$

$$(h_{\text{пост}})_i = \alpha L_{\text{пост}}(T_{\text{пост}})_i\,, \tag{5}$$

where α is the coefficient of linear thermal expansion of brickwork ($\alpha=5.5\cdot10^{-6}$ $C^{-1}$); $L_{building}$ and $L_{post}$. – respectively, the height of the capital wall on which the antenna pedestal is placed and the height of the pedestal itself above the capital wall ($L_{building}$ = =6.05 m, $L_{post}$. = 4.55 m); and $(T_{building})_i$ and $(T_{post})_i$ – accordingly, the annual course of temperature inside the building and outside (the temperature of the pedestal of the GNSS station antenna).

Fig. 7 shows the average seasonal vertical movement of the GNSS station for the observation periods of 2004–2005 and 2018–2019, which are calculated by the method presented above.

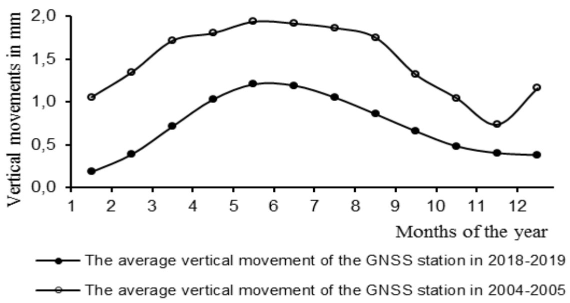



*Fig. 7. Seasonal vertical movements of permanent "POLV" GNSS stations*

The oscillation of the antenna of the GNSS station is about 1 mm, and its maximum rise occurs at the end of May. It should be noted the invariance of the numerical characteristics of the seasonal component of vertical movements during both cycles of observations.

To obtain a reliable connection between the height systems of 2004–2005 and 2018–2019, several parallel determinations of the heights of the old and new marks were made. Fig. 8 shows the slow movements of the GPS station in Poltava for the period 2004–2019 relative to the initial benchmark A1, as well as the linear trend of these movements.

According to Fig. 8, there is a slightly slow local rise of the "POLV" GNSS station, the numerical characteristics of which are given in the table. 1.

The obtained results indicate the high resistance to the slow local movements of the building, on which a permanent international GNSS station is installed, as well as its absence of slopes since the rate of rise is practically the same according to the results of observations of both leveling marks.

According to satellite data EUREF Permanent GNSS Network. Position Time Series, which was continuously delivered to the server, including the European EPN network, it is possible to observe the displacement of the station in three directions over a long period (Fig. 9).

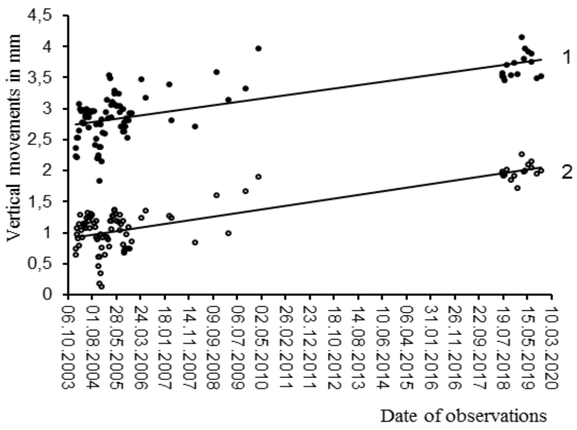



*Fig. 8. Slow movements of the permanent GNSS station in Poltava: 1 – according to the observations of the E mark, 2 – according to the observations of the W mark*

Since the satellite data is constantly changing, the third-degree polynomial smoothing approximation method was used for processing. As a result of the approximation of the vertical movements of the "POLV" GNSS station, trend lines were constructed (Fig. 10).

For the observation period of 2004–2005, the level of approximation reliability is 0.058; the function describing this type of smoothing is $z = 0.0002t^3 - 0.5721t^2 + 726.2t - 0.3*10^6$.

For the observation period of 2018–2019, the level of approximation reliability is 0.3022; the function describing this type of smoothing is $z = -0.0006t^3 + 3.733t^2 - 7486.2t + 5*10^6$.

For the observation period 2019–2020, the level of approximation reliability is 0.4542; the function describing this type of smoothing is $z = -0.0002t^3 + 1.0686t^2 - 2{,}189.6t + 1*10^6$.

For the observation period of 2020–2021, the level of approximation reliability is 0.2245; the function describing this type of smoothing is $z = -0.0004t^3 + 2.4951t^2 - 5260.3t + 4*10^6$.

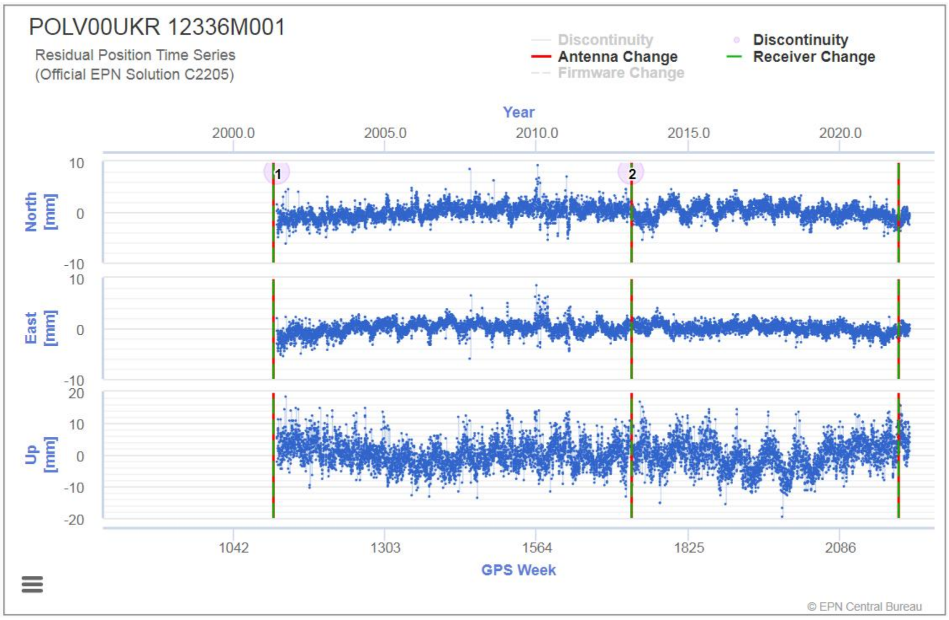



*Fig. 9. Satellite data of the EUREF Permanent GNSS Network regarding the movements of the GNSS station POLV*

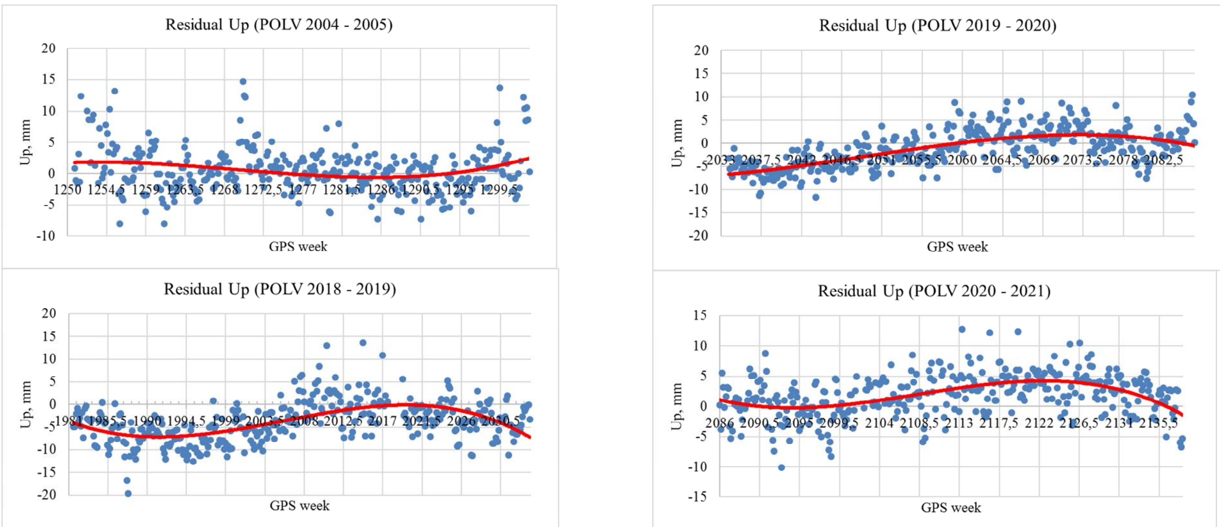



*Fig. 10. Vertical movements of the POLV GPS station from 2004 to 2005 and from 2018 to 2021 according to satellite observations [EUREF Permanent GNSS Network. Position Time Series]*

*Table 1*

**Numerical characteristics of slow vertical movements of the GNSS station "POLV" due to the action of local hydrothermal factors**

| For results observations | Slow vertical movements | |
|---|---|---|
| | for the period 2004–2019, mm | average annual speed rise, mm per year |
| Eastern mark E | 1.03 | 0.065 |
| Western brand W | 1.11 | 0.070 |

According to the trend directions in Fig. 10 in the period of 2004–2005, the average fluctuation of "POLV" was up to 2 mm, in the period of 2018–2019, such fluctuations increased to 7 mm. The limit values of the vertical movements of the GNSS station POLV are given in Table 2.

The IGS/EPN station is a source of high-precision coordinates in the universal coordinate systems WGS-84/ITRF-XXXX and others 3 mm (UPC) for planned coordinates and 3–5 mm for height (after a certain period of observations) [Zhalilo, 2017].

Observations of the station to perform high-precision coordinate determinations in differential mode are provided in international formats: RINEX 2.10 (and above) – standards of observation files intended for post-session processing (user access is via FTP-server); NTRIP 1.0 (or higher) – transport protocol for the transmission of differential DGPS/RTK – real-time corrections via the Internet (user access is via NTRIP-Caster Laboratories) – optional. Satellite data of the "POLV" GNSS station, which were sent to the server of the European Network EPN, are characterized by a high spread of up to ±20 mm. However, after performing the approximation, the amplitude of oscillations decreased to 2 mm in the period 2004–2005 and to 7 mm in the period 2018–2019.

The official speeds of the station, published by EUREF, are summarized in the Table 3.

*Table 2*

**Limit values of vertical movements of GNSS station POLV**

| Years of observation | 2004–2005 | 2018–2019 | 2019–2020 | 2020–2021 | 2001–2022 |
|---|---|---|---|---|---|
| Max, mm | +14.7 | +13.6 | +10.5 | +12.8 | +18.5 |
| Min, mm | -8.0 | -19.7 | -11.7 | -10.1 | -19.7 |

*Table 3*

**The official speeds of the station, published by EUREF**

| Frame | $V_{North,}$ mm/year | $V_{East}$, mm/year | $V_{Up}$, mm/year |
|---|---|---|---|
| IGb14 | 12.33 ±0.01 | 22.44 ± 0.00 | -0.02 ±0.02 |
| ETRF2014 | 0.32 ±0.01 | -1.72 ± 0.00 | -0.06 ±0.02 |

**Scientific novelty and practical significance**

The scientific novelty lies in the detected stability of the amplitude of vertical movements of the GNSS station "Poltava" (identifier POLV), which was confirmed by the ground method of geometric leveling and the analysis of time series of satellite observations. The conducted studies confirm the influence of various factors on the stability of receiving antennas.

**Conclusion**

The vertical component of the dynamics of the earth's surface is the most sensitive to the action of external factors of hydrometeorological origin. The observations by ground geodetic methods for the period 2004–2019 show that the stationary GNSS station POLV is characterized by high resistance to local deformations of the upper soil layer. Its seasonal fluctuations reach 2 mm, and the slow trend does not exceed 0.07 mm/year. There is an increase in the point in the first half of the year and a decrease in the second. The reliability of the determination of the height component was confirmed by the results of satellite observations. The paper compared the results of ground and satellite observations for the periods of 2004–2005 and 2018–2019. According to observations and simulations, the component of vertical oscillations of the receiving antenna, obtained in 2004–2005 by terrestrial and satellite methods, did not exceed 2 mm; in the period of 2018–2019, the analysis of satellite data showed an increase in fluctuations up to 7 mm. This can be explained by a large spread of satellite measurements. Selected components that can affect the vertical movements of a GNSS station are installed on an engineering structure.

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## АНАЛІЗ ВЕРТИКАЛЬНИХ РУХІВ ПЕРМАНЕНТНОЇ ГНСС-СТАНЦІЇ POLV НА ОСНОВІ СУПУТНИКОВИХ ДАНИХ ТА НІВЕЛЮВАННЯ

Метою роботи є аналіз результатів дослідження динаміки вертикальних рухів перманентної станції системи позиціонування ГНСС "Полтава" (ідентифікатор POLV). Методика. На території Полтавської гравіметричної обсерваторії розбитий геодинамічний полігон. Він включає репери з відомими показниками стійкості, які закладені на різній глибині. На репері А1, який відзначається високою стійкістю впродовж 30 років спостережень, встановлено точний нівелір Н–05. ГНСС-станція, вертикальні рухи якої досліджувалися, розташована на спеціально збудованому постаменті на внутрішній капітальній стіні лабораторного корпусу Полтавської гравіметричної обсерваторії Інституту геофізики імені С. І. Субботіна НАН України. Динаміку руху базової станції спостерігали за марками, закладеними на краях західної та східної сторін лабораторного корпусу. Для оцінки й порівняння отриманих результатів виконана обробка супутникових даних методом апроксимації поліноміального згладжування третього ступеню. За результатами періодичного геометричного нівелювання встановлено, що за період 2004–2019 рр. повільні вертикальні рухи марок становили 1,03–1,11 мм з середньорічною швидкістю підняття 0,065–0,07 мм/рік. Сезонні вертикальні рухи перманентної ГНСС-станції POLV – в межах 2 мм/рік, водночас у першому півріччі спостерігається підняття пункту, а в другому – його опускання. Виділено складові, що можуть впливати на вертикальні рухи ГНСС-станції, яка встановлена на інженерну споруду. Порівняння результатів наземними і супутниковими спостереженнями здійснено за періоди 2004–2005 рр. і 2018–2019 рр. На основі виконаних спостережень та моделювання складова вертикальних коливань приймальної антени, отримана у період 2004–2005 рр. і наземними, і супутниковими методами, не перевищувала 2 мм; у період 2018–2019 рр. аналіз супутникових даних показав збільшення коливань до 7 мм, це можна пояснити високим розкидом супутникових вимірювань. Наукова новизна та практична значущість полягають у виявленій стабільності амплітуди вертикальних рухів ГНСС-станції "Полтава" (ідентифікатор POLV), що підтверджено наземним методом геометричного нівелювання і аналізом часових рядів супутникових спостережень. Виконані дослідження підтверджують вплив різних чинників на стійкість приймальних антен.

*Ключові слова*: глобальні навігаційні супутникові системи (ГНСС), постійно діючі (перманентні) станції, приймальні антени, вертикальні зміщення, геометричне нівелювання, дані супутникових спостережень.

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