GEODESY

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METROLOGICAL CHARACTERISTICS DIAGNOSIS OF HIGH-PRECISION GNSS OBSERVATIONS BY METHODS OF NON-CLASSICAL ERROR THEORY OF MEASUREMENTS

The aim of the research is to diagnose the metrological characteristics of high-precision GNSS-observations by methods of non-classical error theory of measurements (NETM) based on Ukrainian reference stations. Methodology. We selected 72 GNSS reference stations, downloaded daily observation files from the LPI analysis center server, and created time series in the topocentric coordinate system. The duration of the time series is almost two years (March 24, 2019 - January 2, 2021). Using a specialized software package, the time series have been cleaned of offsets and breaks, seasonal effects, and the trend component has been removed. Verification of empirical distributions of errors was provided by the procedure of NETM on the recommendations offered by G. Jeffries and on the principles of hypothesis tests the theory according to Pearson's criterion. The main result of the research. It is established that the obtained time series of coordinates of reference GNSS stations do not confirm the hypothesis of their conformity to the normal Gaussian distribution law. NETM diagnostics of the accuracy of high-precision GNSS measurements, which is based on the use of confidence intervals for assessing the asymmetry and kurtosis of a significant sample, followed by the Pearson test, confirms the presence of weak, not removed from GNSS-processing, sources of systematic errors. Scientific novelty. The authors use the possibility of NETM to improve the processing of high-precision GNSS measurements and the need to take into account the sources of systematic errors. Failure to take into account certain factors creates the effect of shifting the time coordinate series, which, in turn, leads to subjective estimates of station velocity, i.e. their geodynamic interpretation. Practical significance. Research of the reasons for deviations of errors distribution from the established norms provides metrological literacy of carrying out high-precision GNSS measurements of large samples.

Key words: Gaussian error laws, Pearson-Jeffries error laws; non-classical error theory of measurements (NETM); GNSS measurements; reference station.

Introduction

Long-term time series of GNSS stations have been widely used to monitor Earth's movements (for example, plate tectonics, sea level changes, pole motion studies, etc.). First of all, long-term GNSS observations from the permanent and reference stations allow us to determine the global and local movement of tectonic plates, as well as to identify seasonal fluctuations [Maciuk, et al., 2021]. The velocities of tectonic plates obtained from coordinate time series are regularly used as input data for geophysical models. However, as numerous studies show, the coordinate time series contain significant additional annual and semi-annual signals, as well as “local” systematic signals, which can significantly affect the reliability of the obtained velocity estimates. [Blewitt, Lavallée, 2002].

In the general case, for high-precision determination of coordinates, it is necessary to use GNSS measurements obtained as a result of estimating the delay of the navigation signal propagation in the phase of carrier oscillations, which are the result of measurements of current navigation parameters – code and phase pseudo-distances.

The main errors of GNSS measurements are related to:

- the difference in time scales between the user's receiver and a particular GNSS;
- divergence of time scales between a particular navigation satellite and its navigation system;
- delayed propagation in the ionosphere of the radio signal of each satellite to the user

receiver in the operating frequency range, for example, L1 and L2;

- delay in the propagation of the radio signal in the Earth's troposphere;
- integer ambiguity of pseudo-phase measurements [Karaim, et al., 2018].

It means that it is necessary to take into account various systematic influences for the processing of such time series of GNSS measurements with residual unaccounted for systematic errors by the methods of the non-classical error theory of measurements (NETM). But, in our opinion, the main component of these changes is the metrological situation around specific observation stations. Another reason for annual signals from the global frame of reference is the surface load due to hydrology and atmospheric pressure. The study (Van Dam, et al., 2001) showed that hydrological models (also taking into account atmospheric load) strongly correlate with time series of coordinates, with a decrease in the variance of the residual heights approximately equal to the variance of these models. Therefore, seasonal changes, which are best described with the help of a deterministic model, are likely to contribute to the error of determining the rate of change of coordinates, especially for short-term GNSS observations. As long as the physical models of the annual signals do not representatively describe the observed changes, a reasonable solution to this problem is to estimate the annual signal simultaneously with the station velocity and the initial coordinates. Another strategy is to use, for example, spatio-temporal filtration [Wdowinski, et al., 1997], which will not be effective enough for large regions, or studies of the stability of major tectonic plates.

It should also be noted that geodetic surveys almost always rely on an accurate global reference frame ITRS/ITRF. For example, such a reference frame is important for accurate satellite orbits created by the International GNSS Service (IGS), Earth rotation parameters created by the International Earth Rotation Service and reference systems (IERS), global reference station coordinates, and rates of change to determine the kinematics of relatively stable tectonic plates for research of deformations. The current procedures for creating implementations of the terrestrial reference system IERS -ITRF do not take into account the annual signals when obtaining the velocity of coordinates changes or even “local systematic signals”.

As a rule, annually repeated signals usually contain not only the annual sinusoidal component but also the annual harmonics. Thus, estimating only the annual amplitude and phase will not mitigate the full effect of this signal.

Depending on the nature of the signal and other factors that cause time series changes, specific methods are needed to distinguish between signals from tectonic movement and other non-tectonic signals, such as seasonal or local changes. These methods can be used both for visual interpretation and time series pre-processing, and statistical analysis for their accuracy and the need to take into account several sources of systematic errors [Jiang, et al., 2017].

Visual interpretation and pre-processing of the obtained time series of coordinates includes detection and removal of shifts, offsets, and breaks, noise characteristics, assessment of the trend and seasonal changes, as well as analysis of residual errors. The most common tools for such purposes are GGMatlab (TSView) [Herring, 2003], FODITS [Ostini, et al., 2008], CATS, Hector, iGPS, and others. The TSView subroutine is a complement to the GAMIT / GLOBK software package, and FODITS is built into the BERNESE software, and standalone CATS programs [Williams, 2008], Hector, iGPS [Tian, 2011], etc.

Regarding statistical analysis on the need to take into account several sources of systematic errors, it is possible to use a wide range of mathematical approaches. One of them is the non-classical error theory of measurements (NETM).

In this article, it is offered to consider concrete concepts of NETM concerning GNSS observations at reference stations of Ukraine for 2019–2020 and to analyze results of researches from the point of view of geodynamic changes of components of topocentric coordinates.

The aim

The purpose of the research is to diagnose the metrological characteristics of high-precision GNSS observations by NETM methods in order to assess the suitability of GNSS stations to solve problems of the highest accuracy as well as geodynamics.

Methodology

Today the reliable accuracy of determining the absolute coordinates of geodetic points from GNSS observations is 1 cm and the velocity is 1–2 mm / year [Dvulit, et al., 2020]. The creation of automated observation systems is the most significant challenge of the modern era, which led to the significant growth of measurements due to their automation and computerization. In practice, this means that Gauss's classical error theory of measurements (CETM) in the processing of large-scale observations can not ensure the effectiveness of the estimate [Dvulit, et al., 2021]. Considering the distributions of observations of large volumes series errors, the English scientist Jeffries made a confident conclusion that with the sample of observations n>500 hypothesis of normality is practically and theoretically impossible because in this case, the measurement errors do not obey Gauss's law. In this case, the errors are subject to the Pearson type VII distribution with a diagonal Fisher information matrix:

$$f(x) = \frac{\Gamma(m+1)}{\sqrt{2\pi(m-0.5}\cdot\Gamma(m+0.5)} \cdot \frac{1}{\sigma} \cdot \left[1 + \frac{0,5}{M}\left(\frac{x-\lambda}{\sigma}\right)^{-2}\right]^{-m}, \quad (1)$$

where $\Gamma(m)$ – gamma function, λ, σ – mathematical expectation and scattering parameter, m – key parameter of the law (1), which is a measure of its deviation from the normal law, $M = (m-0,5)^3 \cdot m^{-2}$.

Now it is necessary to master the processing of observations in non-Gaussian distributions of their errors. The use of the Pearson type VII distribution form allows controlling the absence of non-random, i.e. correlated errors in the results of observations.

Thus, if the errors of large samples obey the Pearson-Jeffries law, the form of this distribution is determined by the magnitude of the value of the kurtosis. It means that each instrument and even the location of the station has values of kurtosis and deviation from Gauss's law, which is characterized by a key metrological characteristic of errors distribution. Based on mass verification of this law due to the results of empirical distributions of errors for economic, space, astronomical, gravimetric, and geodetic studies, it has been established [Dvulit, Dzhun, 2017, Dzhun, 2015]:

1. The value of kurtosis:

a) economics $\varepsilon = 2.895 \pm 0.142$;

b) space $\varepsilon = 1.719 \pm 0.052$;

c) astronomical $\varepsilon = 1.077 \pm 0.015$;

d) gravimetric $\varepsilon = 0.810 \pm 0.105$;

e) geodetic $\varepsilon = 0.767 \pm 0.034$.

2. The asymmetry of these series of observations is small and insignificant.

3. The parameter m, that determines the magnitude of the kurtosis is considered as a measure of the deviation of the Pearson-Jeffries distribution from Gauss's law. Random independent errors at large volumes of measurements (n> 500) obey Pearson-Jeffries law with an exponent within:

$$3 \le m \le 5.$$

4. The effect of unextracted, correlated systematic errors in the results of observations can be neglected only if the confidence interval for their asymmetry covers zero, and the confidence interval for kurtosis covers zero or is in the positive region:

$$A_s = 0; \ \varepsilon_s = 0.$$

5. NETM relies on CETM to further the effectiveness of assessments and improve the processing of high-precision observation results.

We selected 72 Ukrainian GNSS reference stations to verify the conformity of the results of empirical coordinates distributions (topocentric and geocentric) to the Pearson-Jeffries law. The main feature of the choice of stations was the presence of a continuous series of observations.

The Department of Higher Geodesy and Astronomy regularly processes the GNSS observations of the above stations in Ukraine. Processing of GNSS-observation data is carried out in the software package GIPSY-OASIS. Several additional programs are used to create time series, first one total file to select a geocentric series for a particular station and then to convert to a new file with time series in the topocentric coordinate system N, E, U.

For the convenience of further analysis, the stations were grouped into blocks according to different characteristics: by the height of the station location, by geographical location, and by the manufacturer (equipment) of the devices installed at the station. The first division into blocks by height has the following blocks: less than 150 m (11 stations), from 150 to 250 m (29 stations), from 250 to 350 m (12 stations), from 350 m (9 stations). The following division by geographical location is as follows: West (24 stations), North Center

(24 stations), South Center (14 stations), and East (8 stations). The division by equipment used at the station has the following blocks: Novatel (27 stations), Leica (12 stations), Trimble (10 stations), Topcon (13 stations). The duration of observations on each of them is 2 years (from March 24, 2019 (2046 GPS week) to January 2, 2021 (2138 GPS week)).

We used the iGPS software package to pre-check the stability of the observation station. The program can automatically select stations with the needed length of observations from the list of stations. Using this software we can determine the presence of a trend component of the time series. If the station time series has a nonlinear offset, it must be removed from processing by <Outlier>. Sometimes some sections of time series are nonlinear or intermittent. In this case, these areas can be removed from the time series. The software also determines and displays on the graphical interface the value of the RMS for each coordinate component separately. For automatic estimation of the linear annual velocity and smaller ranges, we use the utility <Model>. If there are undetected displacements and offsets after using this utility, we can easily detect them by looking at the residual time series graph. We can then manually identify and remove them using the utility <Offset Selector> while saving them in a special offset file.

We use a utility to account for these offsets <Model> again using the offset file. Figure 1 and Figure 2 show a graphical example of BORZ time series before and after applying the "clean" procedures based on iGPS respectively.

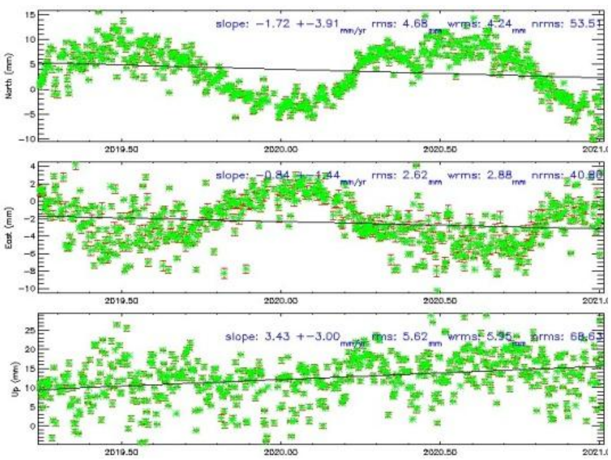

Fig. 1. The "raw" time series of BORZ station

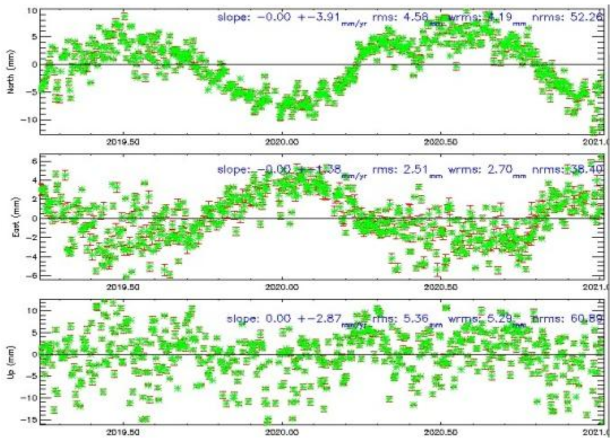

Fig. 2. The "clean" time series of BORZ station

The next step was calculating the mean values of the spatial topocentric coordinates N, E, U (ITRF2014, t) and the error of the deviations of each individual value from the sample mean. Thus, we obtained time series empirical errors in determining the spatial topocentric coordinates of the appropriate stations.

Results and Discussion

Any deviation of their true distribution from the ideal mathematical form is caused by the action of systematic errors, which become noticeable in a large number of observations. These deviations are expressed by the values of asymmetry and kurtosis of the true error distribution. If the weight function is non-singular, provided

$$A = 0 \text{ ;i } e \geq 0. \quad (2)$$

Then any deviation from these conditions will be evidence of the strong and unacceptable influence of the systematic error variables.

To verify that the obtained observation results fall within the permissible estimate A, it is necessary to construct confidential intervals for the asymmetry and the kurtosis values of errors, that can be obtained from unbiased moment estimates:

$$A = \frac{\sqrt{n\,(n-1)}}{n-2}\frac{m_3}{m_2^{1.5}} \;; \quad (3)$$

$$e = \frac{(n-1)(n^2-2n+3)}{n(n-2)(n-3)}\frac{m_4}{m_2^2} - \frac{3(n-1)(2n-3)}{n(n-2)(n-3)} - 3, \quad (4)$$

where n is a sample, m_r represent the sample center moments of order r, calculated by measurement results of x_i:

$$m_r = n^{-1}\sum(x_i - \overline{x})^r;\ \overline{x} = n^{-1}\sum x_i, \quad (5)$$

where x_i is the station coordinates, $\overline{x}$ is an average coordinate value.

We use the standard errors of these statistics to construct confidential intervals for asymmetry and kurtosis:

$$s_A = \sqrt{\frac{4m_2^2m_6 - 12m_2m_3m_5 - 24m_2^3m + 9m_3^2m_4 + 35m_2^2m_3^2 + 36m_2^5}{4m_2^5n}}; \quad (6)$$

$$s_e = \sqrt{\frac{m_2^2m_8 - 4m_2m_4m_6 - 8m_2^3m_3m_5 + 4m_4^3 - m_2^2m_4^2 +}{m_2^6n}\sqrt{16m_2m_3^2m_4 + 16m_2^3m_3^2}}, \quad (7)$$

where m_r is the center moments of order r, n is a sample.

Having received the value A, $\mathcal{E}$, σA, $\sigma\mathcal{E}$ by formulas (3–4, 6–7), defining confidential intervals for A and $\mathcal{E}$:

$$A \pm t_a \cdot s_A;\ e \pm t_a \cdot s_e, \quad (8)$$

where t_a quantile, determined by the Laplace function for the significance level α; s_A and s_e calculated by the formulas 5 and 6.

If the confidence intervals cover zero, then it is possible to limit ourselves to the methods of estimating the NETM, during GNSS measurements. All other cases will indicate different deviations in the station operation or a harsh, unacceptable deterioration of the observing conditions.

The results of our studies are shown in Tables 1, 2, and 3. They give confidence intervals for asymmetry and excess for each component of coordinates, as well as the number (N) of negative and positive values of these intervals.

According to the theory of testing Neumann-Pearson hypotheses, if the confidence intervals cover zero, it is a necessary and, as a rule, a sufficient sign of the normality of measurement errors. If, however, at least one confidence interval does not cover zero, then to solve the question of nonsingularity or singularity of the weight function, we must remember that only the laws of Gauss and Pearson-Jeffries provide the possibility of obtaining nondegenerate estimates in the mathematical data processing [Dvulit, Dzhun, 2019].

Table 1

Confidential intervals for A and $\mathcal{E}$ depending on the height of the selected GNSS reference stations

H, m		Confidential intervals for A_s				Confidential intervals for e_s			
		Negative	N	Positive	N	Negative	N	Positive	N
0-150	N	$-0.436<A_s<-0.048$	9	$0.003<A_s<0.676$	11	$-0.732<e_s<-0.265$	5	$0.052<e_s<2.002$	15
	E	$-0.977<A_s<-0.040$	15	$0.201<A_s<0.706$	5	$-0.630<e_s<-0.170$	4	$0.246<e_s<2.439$	16
	U	$-0.488<A_s<-0.003$	6	$0.009<A_s<0.629$	14	-0.088	1	$0.056<e_s<2.773$	19
150-250	N	$-0.583<A_s<-0.017$	25	$0.025<A_s<0.930$	33	$-1.299<e_s<-0.065$	18	$0.008<e_s<2.790$	40
	E	$-1.228<A_s<-0.001$	25	$0.000<A_s<0.887$	33	$-1.344<e_s<-0.017$	17	$0.006<e_s<4.469$	41
	U	$-0.573<A_s<-0.003$	30	$0.035<A_s<0.640$	28	$-1.377<e_s<-0.004$	19	$0.001<e_s<2.212$	39
250-350	N	$-0.507<A_s<-0.021$	10	$0.033<A_s<0.843$	14	$-0.754<e_s<-0.011$	8	$0.083<e_s<2.468$	16
	E	$-0.579<A_s<-0.010$	7	$0.001<A_s<0.928$	17	$-0.868<e_s<-0.028$	8	$0.050<e_s<3.422$	16
	U	$-0.559<A_s<-0.064$	11	$0.000<A_s<0.770$	13	$-1.117<e_s<-0.142$	5	$0.076<e_s<2.433$	19
More 450	N	$-0.817<A_s<-0.077$	13	$0.009<A_s<0.325$	7	$-1.256<e_s<-0.008$	6	$0.066<e_s<1.745$	14
	E	$-0.414<A_s<-0.072$	5	$0.061<A_s<1.323$	15	$-0.626<e_s<-0.253$	2	$0.264<e_s<4.747$	18
	U	$-1.017<A_s<-0.244$	11	$0.019<A_s<0.569$	9	$-1.352<e_s<-0.327$	4	$0.156<e_s<3.188$	16

Table 2

Confidential intervals for A and $\mathcal{E}$ depending on the geographical location of the selected GNSS reference stations

Part		Confidential intervals for A_s				Confidential intervals for e_s			
		Negative	N	Positive	N	Negative	N	Positive	N
West	N	$-0.817<A_s<-0.030$	25	$0.009<A_s<0.834$	23	$-1.299<e_s<-0.008$	10	$0.066<e_s<2.468$	38
	E	$-0.689<A_s<-0.010$	14	$0.001<A_s<1.323$	34	$-1.344<e_s<-0.052$	5	$0.144<e_s<4.745$	43
	U	$-1.017<A_s<-0.030$	29	$0.000<A_s<0.569$	19	$-1.377<e_s<-0.327$	6	$0.156<e_s<3.188$	42
North-Center	N	$-0.583<A_s<-0.017$	20	$0.035<A_s<0.930$	26	$-1.125<e_s<-0.065$	12	$0.008<e_s<2.790$	34
	E	$-1.228<A_s<-0.001$	17	$0.000<A_s<0.887$	29	$-0.863<e_s<-0.017$	15	$0.006<e_s<4.469$	31
	U	$-0.425<A_s<-0.003$	18	$0.058<A_s<0.640$	28	$-0.775<e_s<-0.004$	16	$0.001<e_s<1.374$	30
South-Center	N	$-0.550<A_s<-0.021$	12	$0.033<A_s<0.676$	16	$-0.754<e_s<-0.011$	10	$0.072<e_s<2.002$	18
	E	$-0.977<A_s<-0.024$	15	$0.089<A_s<0.545$	13	$-0.868<e_s<-0.028$	9	$0.050<e_s<3.111$	19
	U	$-0.537<A_s<-0.029$	14	$0.009<A_s<0.770$	14	$-1.117<e_s<-0.142$	8	$0.010<e_s<2.142$	20
East	N	$-0.351<A_s<-0.078$	7	$0.003<A_s<0.468$	9	$-0.732<e_s<-0.194$	7	$0.047<e_s<1.042$	9
	E	$-0.933<A_s<-0.040$	11	$0.198<A_s<0.631$	5	$-0.630<e_s<-0.170$	4	$0.144<e_s<2.074$	12
	U	$-0.156<A_s<-0.050$	4	$0.145<A_s<0.912$	12	-0.088	1	$0.203<e_s<2.773$	15

Table 3

Confidential intervals for A and $\mathcal{E}$ depending on the equipment of the selected GNSS reference stations

Equip		Confidential intervals for A_s				Confidential intervals for e_s			
		Negative	N	Positive	N	Negative	N	Positive	N
novatel	N	$-0.753<A_s<-0.038$	24	$0.003<A_s<0.678$	30	$-1.256<e_s<-0.050$	30	$0.014<e_s<1.312$	24
	E	$-0.691<A_s<-0.018$	23	$0.014<A_s<0.758$	31	$-0.630<e_s<-0.028$	17	$0.006<e_s<3.111$	37
	U	$-0.594<A_s<-0.029$	27	$0.009<A_s<0.629$	27	$-1.352<e_s<-0.004$	16	$0.056<e_s<3.188$	38
leica	N	$-0.358<A_s<-0.017$	10	$0.061<A_s<0.930$	12	$-0.424<e_s<-0.011$	2	$0.008<e_s<2.790$	20
	E	$-1.228<A_s<-0.001$	15	$0.097<A_s<0.437$	7	$-0.802<e_s<-0.199$	5	$0.179<e_s<4.469$	17
	U	$-0.470<A_s<-0.030$	7	$0.064<A_s<0.621$	15	$-0.831<e_s<-0.143$	4	$0.077<e_s<2.212$	18
trimble	N	$-0.817<A_s<-0.021$	12	$0.040<A_s<0.834$	8	-0.065	1	$0.066<e_s<2.468$	19
	E	$-0.980<A_s<-0.052$	6	$0.000<A_s<1.323$	14	$-0.868<e_s<-0.052$	5	$0.290<e_s<3.786$	15
	U	$-0.635<A_s<-0.036$	10	$0.000<A_s<0.640$	10	$-0.664<e_s<-0.067$	4	$0.076<e_s<3.010$	16
topcon	N	$-0.512<A_s<-0.048$	13	$0.022<A_s<0.587$	13	$-1.299<e_s<-0.194$	4	$0.070<e_s<1.862$	22
	E	$-0.933<A_s<-0.010$	7	$0.085<A_s<0.928$	19	$-1.344<e_s<-0.017$	5	$0.144<e_s<2.790$	21
	U	$-0.559<A_s<-0.003$	12	$0.085<A_s<0.561$	4	$-1.377<e_s<-0.052$	4	$0.001<e_s<2.773$	22

The distribution of stations according to the above criteria did not show any features in the distribution of coordinate errors. Therefore, we can conclude that the results obtained depend on the local characteristics of the stations.

If the estimates of the parameters are derived from the general set of individual values of a random variable that obeys the normal distribution law, then this is not a guarantee that the estimates themselves also have a normal distribution.

Note that the calculated confidence intervals for the asymmetry as a whole for most of the components of the topocentric coordinates of the reference stations cover zero, which confirms the hypothesis $A=0$. Confidence intervals for the excess of the corresponding components of the coordinates are in the positive region, which confirms the hypotheses: $A=0$, $e>0$.

For this case, the weight function of the empirical distribution is not singular, which means that the estimate is acceptable but the distribution of errors is not ideal, because it confirms the effect of weak, not excluded systematic errors. To improve the quality of estimates, the following approximation is needed to estimate the parameters of the mathematical model using NETM methods.

Conclusions

Based on the analysis of the obtained results, we made the following conclusions:

1. After applying the procedures of "cleaning" time series based on the software package iGPS, we obtained a decrease in the values of the RMS for all stations by an average of 5–15 %. Based on these values, it can be concluded that the effect of unexploited or incorrectly simulated errors can significantly affect the results of observations.

2. The analysis of the time series of Ukraine reference stations based on high-precision GNSS measurements did not confirm the hypothesis of their conformity to the normal Gaussian distribution law.

3. All empirical characteristics of time series show that the distribution of errors is not perfect, because it confirms the effect of weak, unaccounted for sources of systematic errors.

4. From the point of view of classical error theory of measurements (CETM), measurements at stations are satisfactory: asymmetry is insignificant in all cases, and confidential intervals cover zero only in 44 % of cases for the North component, 41% for the East component and 52 % for the Up component.

5. The real distribution of measurement errors is not conforming to the normal distribution law, but corresponds to the outdated notions of the classical error distribution law.

6. Further work will focus on identifying the reasons that distort the real distribution, to bring its form to the ideal, and asymmetry and kurtosis to the appropriate limits of the Pearson-Jeffries VII type law.

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ДІАГНОСТИКА МЕТРОЛОГІЧНОЇ ХАРАКТЕРИСТИКИ ВИСОКОТОЧНИХ GNSS-СПОСТЕРЕЖЕНЬ МЕТОДАМИ НЕКЛАСИЧНОЇ ТЕОРІЇ ПОХИБОК ВИМІРІВ

Мета дослідження – провести діагностику метрологічної характеристики високоточних GNSS-спостережень методами некласичної теорії похибок вимірів (НТПВ) на прикладі референцних станцій України. Нами було підібрано 72 референцні GNSS-станції України, завантажено добові файли спостережень із серверу центру аналізу LPI, та створено часові серії в топоцентричній системі координат. Тривалість часових серій становить майже два роки (24 березня 2019–2 січня 2021). Із використанням спеціалізованого програмного пакету виконали очищення часових серій від вискоків, розривів, сезонних впливів, та вилучено трендову складову. Перевірка емпіричних розподілів похибок забезпечувалася процедурою некласичної теорії похибок вимірів на основі рекомендацій, запропонованих Г. Джеффрісом і на принципах теорії перевірок гіпотез за критерієм Пірсона. Встановлено, що отримані часові серії координат на більшості референцних GNSS-станцій не підтверджують гіпотезу про їх підпорядкування нормальному закону розподілу Гаусса. Проведення НТПВ-діагностики точності високоточних GNSS-вимірів, яка ґрунтується на використанні довірчих інтервалів для оцінок асиметрії і ексцесу значної вибірки із наступним застосуванням – тесту Пірсона, підтверджує наявність слабких, не вилучених із GNSS-опрацювання джерел систематичних похибок. Авторами задіяна можливість НТПВ для вдосконалення методики опрацювання високоточних GNSS-вимірів та необхідність врахування джерел систематичних похибок. Неврахування окремих факторів породжують ефект зміщення часового координатного ряду, що, своєю чергою, зумовлює суб’єктивні оцінки швидкостей руху станції, тобто їхню геодинамічну інтерпретацію. Дослідження причин відхилень розподілу похибок від встановлених норм забезпечує метрологічну грамотність інтерпретації високоточних GNSS-вимірів великого обсягу.

Ключові слова: закони похибок Гаусса; Пірсона-Джеффріса; некласична теорія похибок вимірів (НТПВ); GNSS-виміри; референцна станція.

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