https://doi.org/10.33271/nvngu/2022-3/146

Elmira Orynbassarova[1],
orcid.org/0000-0001-6421-4698,
Ainur Yerzhankyzy[1],
orcid.org/0000-0003-2559-3220,
Roman Shults[2],
orcid.org/0000-0003-2581-517X,
Keniel Roberts[3],
orcid.org/0000-0003-2061-7131,
Anuar Togaibekov[4],
orcid.org/0000-0002-5634-8140

1 – Satbayev University, Almaty, the Republic of Kazakhstan, e-mail: e.orynbassarova@satbayev.university
2 – Michigan Technological University, Houghton, MI, USA, e-mail: rshults@mtu.edu
3 – University of Technology, Kingston, Jamaica
4 – University of Grenoble Alps, Grenoble, the French Republic

STRATEGIES OF GNSS PROCESSING AND MEASURING UNDER VARIOUS OPERATIONAL CONDITIONS

Purpose. GNSS technology is one of the key elements of maintenance of the mining works. Mostly, the GNSS observations in mining regions are accomplished under adverse surveying conditions. The presented paper is aimed at studying the problem of GNSS accuracy under various adverse operational conditions that may encounter during surveying works in deposit fields and downgrade the GNSS accuracy.

Methodology. Despite the well-defined problem of GNSS accuracy, each year, new receiver models and software versions come into use, which in turn, needs a more profound analysis of their reliability, accuracy, and efficiency. This study provides relevant information about the static tests that were executed in the canopy, multipath, and open environments to assess the performance of the user segment from different manufacturers. The equipment of three manufactures was tested: Leica, Trimble, and Javad. The test results for two satellite systems, GPS and GLONASS, are presented.

Findings. The obtained results can be generalized to the following outputs. Trimble performed the best on the canopy site in terms of position quality and fix solution. Javad had the best agreement for horizontal, height, and 3D solutions between dual and single frequency processing on the multipath site. On the open spot, Leica's horizontal solution between dual and single frequency processing was the most consistent. It is challenging to state which receiver performed better in the vegetation cover.

Originality. The study aims to develop a general procedure to estimate the accuracy of different GNSS processing strategies under different environments.

Practical value. The given research has a strong hands-on background insofar as the principal stress is made on field measurements. The research results can be employed to refine the GNSS surveying workflow for open-pit mines.

Keywords: *multipath, canopy site, static survey, GNSS, precision positioning*

Introduction. Global Navigation Satellites Systems (GNSS) is the comprehensive name for different satellites GLONASS, Beidou, and Galileo. There are also regional systems such as IRNSS. The basic segments of GNSS are the space, control, and user segments. The fundamental and groundbreaking results have been reached out thanks to the studies of the well-known scientists. Among those it is worth to mention Hofmann-Wellenhof, B., Wasle, H. L., Parkinson, B. W., Spilker J. J. Jr., Wang, J., Satirapod, C., Rizos, C. Over the past decade, the user segment has been enhanced and is now more affordable. Thus, in this contemporary era, GNSS is a multifaceted tool that spans across a wide range of applications such as mining surveying, terrestrial, air and sea navigation, surveying and mapping, recreation, agriculture, military, and geodynamics. Each application requires a different degree of accuracy; therefore, different strategies are used to determine the solution of a position. These techniques include single point positioning, relative positioning, and Precise Point Positioning (PPP). Positioning using the relative and PPP can be achieved in real-time or post-processed. Although GNSS has become an appreciated tool for positioning the ideal conditions for "accurate" positioning is a clear view of the sky (that is minimal or no obstruction) which is not often the case. Hence it is critical to gain sufficient knowledge to identify the possibilities and limitations of different GNSS positioning techniques for different applications under different circumstances [1–3]. Among various applications, GNSS plays an important role in the maintenance of mining operations especially as a main data source for the prediction of the rock structure movements and complement acoustic monitoring methods [4–6] and geomechanical modeling [7]. Mostly, the GNSS observations in mining regions is being accomplished in adverse surveying conditions. These conditions may lead to unallowable accuracy decreasing during surveying works in open-pit mines. When developing mineral deposits on the territory of water bodies, GNSS observations are also used to improve positioning during bathymetrical survey [8].

For the last decades, many publications have been dedicated to the study on GNSS accuracy in different modes. Such studies can be classified into the following groups, just to name a few of the recent: research into the effect of the satellites geometry and receiver location [9–11]; research into multipath influence [12–14], whereas, the comprehend state-of-the-art review of the multipath problem one may find in [2] (Braasch, M. S., 2017); determination of foliage attenuation and its influence on signal degradation; study of multi-constellation solutions for static [15,16], multi-frequency solutions studies [17]; and many studies concerning different receivers [18, 19]. Numerous studies have investigated the problem of processing strategy. The main stress has been given to the issue of the right choice of weight coefficients for baseline processing [20]. Satirapod C. in his works and work with Wang, J. outlined several models for stochastic modeling for precise GNSS carrier phase observations. This list of publications is by no means exhaustive. However, essential questions regarding GNSS accuracy in different modes and conditions remain unanswered. To date, no study has looked specifically at the given problem as a complex issue.

This study provides relevant information about the complex research on GNSS accuracy for static tests that were executed in canopy, multipath and open environment to assess the performance of the user segment from different manufactures for different constellations, and different processing strategies.

The remainder of this paper is structured as follows. Section 2 outlines the data that have been used for the ongoing study, how data were gathered and which software was used for data processing. Section 3 is dedicated to the detailed results review and comprehensive analysis of the obtained results after processing. The final Section 4 deals with conclusions.

Materials and methods. ***Field data collection.*** The canopy site, the multipath and the open site were chosen to execute the static tests. The three GNSS receivers were used to collect data on each site separately for 1 hour. Observations in the multipath environment were repeated the following day 4 minutes earlier (GPS space vehicle ground track repeat) to facilitate correlation in the multipath environment. The data rate for each observation was 1Hz.

To collect the data, the following equipment was used Trimble R8 GNSS combine receiver and antenna No. 3290, Java Triumph-1 combine receiver and antenna No. 00329, Leica GS10-09 kit, Leica GS10-10 kit.

All the selected equipment units are integrated GNSS receivers.

Data processing. Leica Geomatics Office was used to post process the static data for the three receivers.

TEQC was used to perform quality control analysis for the multipath sites. The RINEX data from each receiver was inputted into TEQC which produced output files such as signal to noise on L1 and L2, multipath on L1 and L2, satellite azimuth and elevation data, ionospheric delay observable and derivative of ionospheric delay observable. It also produced a summary file with quality control information.

The multipath data, satellite azimuth and elevation data from TEQC were processed in MatLab to produce multipath and SNR polar maps, FFT spectra and elevation plots.

Grid InQuest software was used to convert the geodetic coordinates obtained form LGO for the static tests for each receiver into grid coordinates.

Results and discussions. ***Static results and analysis.*** *Dual frequency solutions.* The position quality results from LGO indicate that the GS10 and R8 had the same horizontal, height, and 3D quality in the multipath environment, which was better than Javad in all cases (Table 1). However, these were all less than a millimeter; thus they are basically of the same quality. In the open sky environment, the GS10 had the best 2D, height and 3D quality, followed by Trimble and Javad respectively. But again, they were all less than a millimeter, hence the differences are insignificant. Trimble R8 had the best 2D, height and 3D quality in the canopy area, followed by Leica and Javad respectively.

With dual-frequency processing, both the R8 and Triumph-1 obtained phase-fix solutions in the canopy environment; therefore, the integer ambiguity for both receivers was resolved with enough confidence. However, the solution from the GS10 was float, hence the integer value for the ambiguity could not be determined. Therefore, with dual-frequency processing, the R8 and Triumph-1 performed better than the Leica on the canopy site in terms of ambiguity resolution. The three receivers used satellites from both GPS and GLONASS constellations in the canopy environment to achieve a solution. Regarding the solutions for the multipath environment, the GS10 was the only receiver to use both GLONASS and GPS constellations.

However, all the receivers obtained fix solutions in this environment. Concerning the open site, all the receivers also achieved phase-fix solutions. The GS10 and Triumph-1 used both GPS and GLONASS satellites to obtain their solutions, while the R8 used only satellites from the GPS constellation.

Point Name Information: *V* – Vegetation/canopy site; *M* – Multipath site; *O* – Open site; 2 – Day of observation during time allotted; *S* – Static positioning; *T* – Trimble R8 GNSS receiver; *L* – Leica GS10 receiver; *J* – Javad Triumph-1 receiver.

Single Frequency Solutions. The position quality results from LGO indicate that the Javad had the best horizontal, height and 3D on the vegetation site, followed by the GS10 and Trimble correspondingly, which were generally the same. For the open and multipath sites, the 2D, height and 3D indicators were less than a millimeter for all the receivers (Table 2).

The constellation used to obtain the results for the single frequency processing was similar to those of the dual-frequency. The Leica was the only receiver to use both constellations in the multipath environment; the Trimble used only GPS satellites in the open area and all the receivers used both constellations for the vegetation site. As it relates to the solution type for the canopy site, the Trimble was the only receiver to achieve a phase-fix solution. Hence it can be inferred that the Trimble performed better than the other receivers on the canopy site in terms of solution type. Regarding the multipath and open sites all the receivers resolved the ambiguities by obtaining phase-fix solutions.

Dual Frequency Solutions Comparative Analysis between Each Receiver. The best northing, easting, and height agreement in the vegetation environment was between the Trimble and Javad resulting in the smallest horizontal and 3D deviation respectively (Fig. 1, right red bars). The worst deviation in northing, easting, and height was between the Trimble and Leica; hence this pair had the largest 2D and 3D deviation. The median separation in both 2D and 3D was between the Leica and Javad (Table 3).

Regarding the multipath site, the smallest variation in easting was between the Trimble and Leica followed by Trimble versus Javad and Javad versus Leica. The best agreement for northing was 0 mm and was obtained from the Trimble versus Javad. The northing separation for Trimble versus Leica and Javad versus Leica were the same. The smallest horizontal deviation was between the Trimble and Leica and the largest horizontal separation was between Javad against Leica. It is worth mentioning that the separation between each pair of the receiver did not exceed 11 mm. Regarding height separation, the deviation between the Trimble and Javad was 3 mm, while the separation between the Trimble against Leica and Javad

Table 1

LGO Dual Frequency Processing Results for Static Positioning

Point	Constellation	Solution	Frequencies	$m_{horizontal}$, m	m_{height}, m
O-2-L-S	GPS/GLONASS	Phase: fix all	L1 + L2	0.000	0.000
O-2-T-S	GPS	Phase: fix all	L1 + L2	0.000	0.000
O-2-J-S	GPS/GLONASS	Phase: fix all	L1 + L2	0.000	0.001
V-2-L-S	GPS/GLONASS	Float	L1 + L2	0.005	0.005
V-2-T-S	GPS/GLONASS	Phase: fix all	L1 + L2	0.001	0.001
V-2-J-S	GPS/GLONASS	Phase: fix all	L1 + L2	0.012	0.031
M-2-L-S	GPS/GLONASS	Phase: fix all	L1 + L2	0.000	0.000
M-2-T-S	GPS	Phase: fix all	L1 + L2	0.000	0.000
M-2-J-S	GPS	Phase: fix all	L1 + L2	0.000	0.000

Table 2

LGO Single Frequency Processing Results for Static Positioning

Point	Constellation	Solution	Frequencies	$m_{horizontal}$, m	m_{height}, m
O-2-L-S	GPS/GLONASS	Phase: fix all	L1	0.0001	0.0001
O-2-T-S	GPS	Phase: fix all	L1	0.0002	0.0003
O-2-J-S	GPS/GLONASS	Phase: fix all	L1	0.0002	0.0003
V-2-L-S	GPS/GLONASS	Float	L1	0.0010	0.0019
V-2-T-S	GPS/GLONASS	Phase: fix all	L1	0.0013	0.0017
V-2-J-S	GPS/GLONASS	Float	L1	0.0005	0.0009
M-2-L-S	GPS/GLONASS	Phase: fix all	L1	0.0001	0.0002
M-2-T-S	GPS	Phase: fix all	L1	0.0001	0.0002
M-2-J-S	GPS	Phase: fix all	L1	0.0002	0.0004

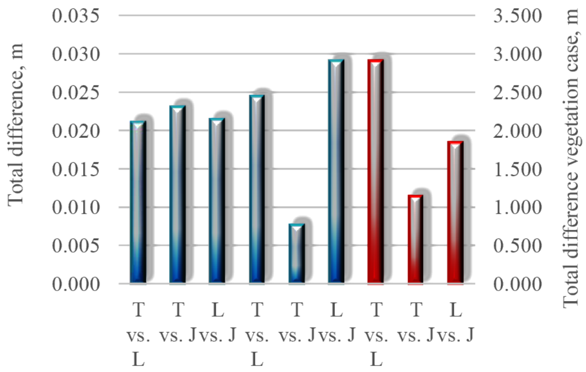

Fig. 1. Dual frequency solutions comparative analysis between each receiver

Table 3

Dual frequency solutions comparative analysis between each receiver

Receivers	ΔE, m	ΔN, m	Δh, m	Δ, m
Trimble vs. Leica	–0.001	–0.001	–0.021	0.021
Trimble vs. Javad	0	0.018	–0.003	0.018
Leica vs. Javad	0.001	0.019	0.018	0.026
Trimble vs. Leica	–0.456	–0.302	0.566	0.787
Trimble vs. Javad	–0.091	–0.125	0.879	0.892
Leica vs. Javad	0.365	0.177	0.313	0.512
Trimble vs. Leica	–0.001	–0.003	–0.029	0.029
Trimble vs. Javad	–0.01	0.002	0.005	0.011
Leica vs. Javad	–0.009	0.005	0.034	0.036

alongside Leica were 24 and 27 mm respectively. The best 3D separation was between the Trimble and Javad followed by the Trimble versus Leica and Javad vs. Leica respectively.

Relating to the open site, the best easting agreement came from the Trimble vs. Leica, followed by Javad vs. Leica and Trimble against Javad individually. The easting separation between each pair did not exceed 5 mm. The smallest variation in northing was 0 mm and came from the Trimble vs. Leica. The separation in northing for both the Trimble vs. Javad and Javad vs. Leica was 19 mm. As it relates to the horizontal separation, there was just 1 mm between the Trimble and Leica solution. But the horizontal deviation between the Trimble and Javad and Javad and Leica was of the order of 19 mm. The smallest height variation was between the Javad against the Leica followed by Trimble vs. Javad and Trimble alongside the Leica correspondingly. All the 3D comparisons were generally of the same degree, with a maximum deviation of about 2 mm.

Single Frequency Solutions Comparative Analysis between Each Receiver. The smallest horizontal variation on the vegetation site was between the Trimble vs. Javad. The Javad against Leica had the median horizontal separation, and Trimble vs. Leica had the largest. The smallest height variation on the canopy site was between Javad vs. Leica, followed by the Trimble vs. Leica and Trimble vs. Javad correspondingly. Concerning 3D positioning, Javad vs. Leica had the smallest deviation, and Trimble vs. Javad had the largest (Fig. 2, rightmost red bar). The Trimble vs. Leica had the second-largest 3D positioning separation (Table 4).

Concerning the multipath site, the smallest horizontal deviation was between the Trimble vs. Leica, while the Trimble vs. Javad and Javad vs. Leica were similar. The Trimble vs. Javad had the best agreement for height, followed by the Trimble alongside the Leica and Javad vs. Leica, respectively. The best 3D positioning agreement was between the Trimble vs. Javad, followed by the Trimble vs. Leica and Javad vs. Leica individually.

Comparison between Single and Dual Frequency Solutions for Individual Receivers. In the vegetation environment, the Trimble horizontal, height and 3D solutions between dual and single frequency results were the most consistent. The Leica had the worst agreement for horizontal, height and 3D solution between dual and single frequency processing. The Javad solutions were the second best. It is worth mentioning that the deviations between solutions obtained in the canopy environment for each receiver using single-frequency for processing were smaller than those obtained when dual-frequency was used (Fig. 3, right red bars).

Regarding the multipath site, the Javad 2D had the best agreement between dual and single frequency results, while the Trimble and Leica were the same. However, there was just a millimeter difference between the Javad and the Trimble and Leica; hence the horizontal solutions are generally the same

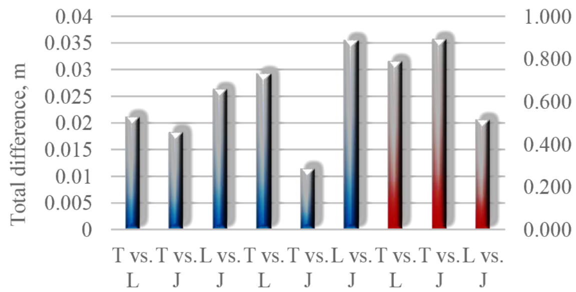

Fig. 2. Single frequency solutions comparative analysis between each receiver

Table 4

Single frequency solutions comparative analysis between each receiver

Receivers	ΔE, m	ΔN, m	Δh, m	Δ, m
Trimble vs. Leica	0.001	0.000	–0.021	0.021
Trimble vs. Javad	0.005	0.019	–0.012	0.023
Leica vs. Javad	0.004	0.019	0.009	0.021
Trimble vs. Leica	–2.182	–1.008	1.634	2.906
Trimble vs. Javad	–0.838	–0.130	0.752	1.133
Leica vs. Javad	1.344	0.878	–0.882	1.832
Trimble vs. Leica	0.003	–0.003	–0.024	0.024
Trimble vs. Javad	–0.007	0.000	0.003	0.008
Leica vs. Javad	–0.01	0.003	0.027	0.029

Table 5

Comparison between single and dual frequency solutions for individual receivers

Receivers	ΔE, m	ΔN, m	Δh, m	Δ, m
O-2-L-S	–0.002	0	0.006	0.006
O-2-T-S	0	0.001	0.006	0.006
O-2-J-S	0.003	0.001	–0.003	0.004
V-2-L-S	–0.516	0.03	–0.123	0.531
V-2-T-S	–2.242	–0.676	0.945	2.525
V-2-J-S	–1.263	0.025	–0.25	1.288
M-2-L-S	–0.002	0.001	0.005	0.005
M-2-T-S	0.002	0.001	0.01	0.010
M-2-J-S	0.001	–0.001	0.003	0.003

for all the receivers. As it relates to the height, the Javad had the smallest separation between dual and single frequency solutions, followed by Leica and Trimble, respectively. The 3D solutions were parallel to the height variations.

In the open area, the smallest horizontal variation between dual and single frequency results was 1 mm, which came from the Leica. The Javad horizontal solution was 2 mm above the Leica. The difference between the dual and single frequency solutions for the Trimble was 18 mm. The Javad 3 mm separation in height between dual and single frequency solutions was the best, followed by the Leica and Trimble correspondingly. The best agreement for a 3D solution between dual and single frequency results was 4.4 mm which came from the Javad. The Leica deviation followed, which was less than 2 mm above the Javad solutions. The Trimble had the worst variation for a 3D solution between dual and single frequency results (Table 5).

Multipath Analysis. It is well-known that multipath is caused by reflecting surfaces such as buildings or water near the GNSS antenna. The reception of multipath signals will degrade position accuracy since it will result in incorrect pseudo-range or carrier measurement. The longer the wavelength of a signal is, the more it will be affected by multipath. That is why multipath will affect the C or P-code signal more than the L1 or L2 carriers. Thus, the basis of the multipath analysis is based on analyzing the coded signals. The multipath analysis results shown in Table 6 indicate that for both sessions, the Leica dominated in the multipath environment on both L1 and L2 followed by Trimble and Javad receivers, respectively. This further explains why the solutions from the Leica and Trimble are closer than those from the Trimble vs. Javad and Javad vs. Leica, which were discussed in subsections *Dual Frequency Solutions Comparative Analysis between Each Receiver* and *Single Frequency Solutions Comparative Analysis between Each Receiver*. The fact that the Leica was the only receiver to use both constellations to generate the solution for dual and

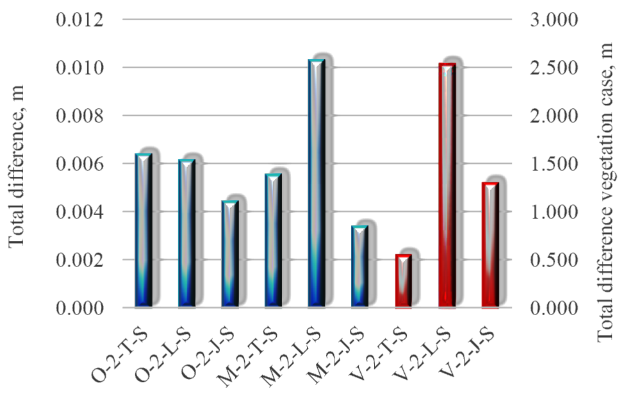

Fig. 3. Comparison between single and dual frequency solutions for individual receivers

Table 6

Multipath results analysis for both sessions for each receiver

Receivers	JAVAD		TRIMBLE		LEICA	
Frequency	L1	L2	L1	L2	L1	L2
Session 1, URMS, m	0.6114	0.7151	0.3463	0.4517	0.0768	0.0305
Session 2, URMS, m	0.4863	0.6114	0.4233	0.4800	0.0931	0.0450

single frequency in the multipath environment may have also contributed to it outperforming the other receivers.

Signal to Noise Ratio. A signal is weak if the carrier to noise power destiny ratio is less than 34 dB HZ. Therefore, signals should be above 34 dB Hz because weaker signals may be prone to more frequent loss of satellite lock, possible loss of satellite lock, or even questionable carrier phase measurement. The signal to noise on L1 and L2 for all the receivers was greater than 34 dB and was generally the same for all the receivers in each session. The Leica had the strongest signal on L1, followed by the Javad and Trimble, respectively. The Javad had the weakest signal on L2, while the Leica and Trimble generally had the same signal strength on L2.

Conclusions. In light of the presented results, a few conclusions can be drawn from the given study. It is evident that canopy and multipath environments negatively affect GNSS by degrading the quality of the navigational solution. The Trimble performed the best on the canopy site in terms of position quality and fix solution, but the Javad had a better precision. The Leica performed the worst on the vegetation site in terms of fix solution and precision. The Leica also had the worst agreement for horizontal, height and 3D solution between dual and single frequency processing on the canopy site. The Trimble, on the other hand, horizontal, height and 3D solutions between dual and single frequency results were the most consistent. On the multipath site, Javad had the best agreement for horizontal, height and 3D solutions between dual and single frequency processing. On the open site, the Leica horizontal solution between dual and single frequency processing was the most consistent, but the Javad 3D was the most stable.

The Leica dominated the multipath environment in both SNR and multipath performance and was the only receiver to use both constellations to generate the solutions for dual and single frequency observables. The Javad had a better overall precision on the multipath site but performed the worst in terms of multipath and SNR. In the open environment the Leica precision was significantly the best, while the Javad precision was the worst.

Future research will have to address GNSS accuracy in more detailed and with extended time on the mining field for investigating deformation monitoring by using static survey. Next studies will have to take processing algorithms that are used in different software into account.

Funding. This research is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP09058620 on the topic: "Web-GIS development based on complex geodynamic monitoring data for Kazakhmys LLP deposit field").

References.

1. Leick, A., Rapoport, L., & Tatarnikov, D. (2015). *GPS Satellite Surveying*. Wiley&Sons. https://doi.org/10.1002/9781119018612.

2. Teunissen, P.J.G., & Montenbruck, O. (Eds.). (2017). *Springer Handbook of Global Navigation Satellite Systems*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-42928-1.

3. Tae, H., Kim, H.-I., & Park, K.-D. (2018). Analysis of Multi-Differential GNSS Positioning Accuracy in Various Signal Reception Environments. *Journal of Positioning, Navigation, and Timing*, *7*(1), 15-24. https://doi.org/10.11003/JPNT.2018.7.1.15.

4. Nurpeissova, M., Bitimbayev, M.Zh., Rysbekov, K.B., Turumbetov, T., & Shults, R. (2020). Geodetic substantiation of the saryarka copper ore region. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *6*(444), 194-202. https://doi.org/10.32014/2020.2518-170X.147.

5. Uteshov, Y., Rysbekov, K., Galiyev, D., Nauryzbayeva, D., & Galiyev, S. (2021). Potential for increasing the efficiency of design processes for mining the solid mineral deposits based on digitalization and advanced analytics. *Mining of Mineral Deposits*, *15*(2), 102-110. https://doi.org/10.33271/mining15.02.102.

6. Sdvyzhkova, O., Golovko, Y., Dubytska, M., & Klymenko, D. (2016). Studying a crack initiation in terms of elastic oscillations in stress strain rock mass. *Mining of Mineral Deposits*, *10*(2), 72-77. https://doi.org/10.15407/mining10.02.072.

7. Shashenko, O.M., Sdvyzhkova, O.O., & Kovrov, O.S. (2010). Modeling of the rock slope stability at the controlled failure, 2010. *Proceedings of the European Rock Mechanics Symposium – Switzerland: European Rock Mechanics Symposium, EUROCK 2010*. Lausanne; Switzerland, 581-584. https://doi.org/10.1201/b10550-138.

8. Kamza, A., Levin, E., Kuznetcova, I., Yerzhankyzy, A., & Orynbassarova, E. (2018). Investigation of changes in DEM, constructed from time to time data from the seabed. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, *18*(2.3), 449-454. https://doi.org/10.5593/sgem2018/2.3/S11.057.

9. Jansson, P., & Persson, C.G. (2013). The effect of correlation on uncertainty estimates – with GPS examples. *Journal of Geodetic Science*, *3*(2), 111-120. https://doi.org/10.2478/jogs-2013-0016.

10. Moore, M., Watson, C., King, M., McClusky, S., & Tregoning, P. (2014). Empirical modelling of site-specific errors in continuous GPS data. *Journal of Geodesy*, *88*(9), 887-900. https://doi.org/10.1007/s00190-014-0729-5.

11. Ma, L., Lu, L., Zhu, F., Liu, W., & Lou, Y. (2021). Baseline length constraint approaches for enhancing GNSS ambiguity resolution: comparative study. *GPS Solutions*, *25*, 40. https://doi.org/10.1007/s10291-020-01071-1.

12. Lau, L., Tateshita, H., & Sato, K. (2015). Impact of Multi-GNSS on Positioning Accuracy and Multipath Errors in High-Precision Single-Epoch Solutions – A Case Study in Ningbo China. *The Journal of Navigation*, *68*(5), 999-1017. https://doi.org/10.1017/S0373463315000168.

13. Cai, C., He, C., Santerre, R., Pan, L., & Cui, X. (2016). A comparative analysis of measurement noise and multipath for four constellations: GPS, BeiDou, GLONASS and Galileo, *Survey Review*, *48*, 1-9. https://doi.org/10.1179/1752270615Y.0000000032.

14. Fuhrmann, T., Garthwaite, M.C., & McClusky, S. (2021). Investigating GNSS multipath effects induced by co-located Radar Corner Reflectors. *Journal of Applied Geodesy*, *15*(3), 207-224. https://doi.org/10.1515/jag-2020-0040.

15. Schönemann, E., Becker, M., & Springer, T. (2011). A new Approach for GNSS Analysis in a Multi-GNSS and Multi-Signal Environment. *Journal of Geodetic Science*, *1*(3), 204-214. https://doi.org/10.2478/v10156-010-0023-2.

16. Abd Rabbou, M., & El-Rabbany, A. (2015). Performance analysis of precise point positioning using multi-constellation GNSS: GPS, GLONASS, Galileo and BeiDou. *Survey Review*, *49*(352), 39-50. https://doi.org/10.1080/00396265.2015.1108068.

17. Hamza, V., Stopar, B., & Sterle, O. (2021). Testing the Performance of Multi-Frequency Low-Cost GNSS Receivers and Antennas. *Sensors*, *21*, 2029. https://doi.org/10.3390/s21062029.

18. Xue, C., Psimoulis, P., & Zhang, Q. (2021). Analysis of the performance of closely spaced low-cost multi-GNSS receivers. *Applied Geomatics*, *13*, 415-435. https://doi.org/10.1007/s12518-021-00361-8.

19. Omirzhanova, Z.T., Kartbayeva, K.T., Aimenov, A.T., & Jazbayev, A.T. (2017). Geodetic measurements of modern movements of the earth surface on almaty geodynamic polygon. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, *17*(22), 337-346. https://doi.org/10.5593/sgem2017/22/S09.042.

20. Gilgien, M., Spörri, J., Limpach, P., Geiger, A., & Müller, E. (2014). The Effect of Different Global Navigation Satellite System Methods on Positioning Accuracy in Elite Alpine Skiing. *Sensors*, *14*, 18433-18453. https://doi.org/10.3390/s141018433.

Стратегії обробки та вимірювання GNSS у різних умовах розробки

Е. Орынбасарова[1], *А. Єржанкизи*[1], *Р. В. Шульц*[2], *К. Робертс*[3], *А. Тогайбеков*[4]

1 – Satbayev University, м. Алмати, Республіка Казахстан, e-mail: e.orynbassarova@satbayev.university

2 – Мічіганський технологический університет, м. Хотон, США, e-mail: rshults@mtu.edu

3 – Технологічний університет Ямайки, м. Кингстон, Ямайка

4 – Університет Гренобль-Альпи, м. Гренобль, Французька Республіка

Мета. Технологія GNSS є одним із ключових елементів технічного обслуговування гірничих робіт. Найчастіше GNSS-спостереження в гірничодобувних районах проводяться у складних геодезичних умовах. Подана робота спрямована на вивчення проблеми точності GNSS за різних несприятливих умов експлуатації, що можуть виникнути під час проведення маркшейдерських робіт на родовищі та призвести до зниження точності GNSS.

Методика. Незважаючи на чітко окреслену проблему точності GNSS, щороку з'являються нові моделі приймачів і версії програмного забезпечення, що, у свою чергу, потребує більш глибокого аналізу їх надійності, точності та ефективності. Це дослідження надає відповідну інформацію щодо статичних тестів, що були виконані в купольному, багатопроменевому й відкритому середовищах для оцінки продуктивності користувацького сегмента від різних виробників. Тестувалося обладнання трьох виробників: Leica, Trimble та Javad. Представлені результати випробувань двох супутникових систем GPS та ГЛОНАСС.

Результати. Отримані результати можна узагальнити такими висновками. Компанія Trimble показала найкращі результати на майданчику з навісом із точки зору якості позиціонування та рішення для фіксації. У Javad було найкраще узгодження рішень по горизонталі, висоті та 3D між двочастотною та одночастотною обробкою на багатопроменевій ділянці. На відкритій місцевості горизонтальне рішення Leica між двочастотною та одночастотною обробкою було найбільш послідовним. Проте, важко сказати, який приймач краще показав себе в умовах густої рослинності.

Наукова новизна. Дослідження спрямоване на розробку загальної процедури з метою оцінки точності стратегій обробки GNSS у різних умовах.

Практична значимість. Це дослідження має сильну практичну основу, оскільки основний акцент було зроблено на польові виміри. Результати дослідження можна використовувати для уточнення робочого процесу GNSS-зйомки на кар'єрах.

Ключові слова: *багатопроменеве поширення, навісний майданчик, статична зйомка, GNSS, точне позиціонування*

The manuscript was submitted 23.10.21.