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Static PPP over observation time using magic-GNSS: GPS Vs. GLONASS Vs. GPS+GLONASS

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Abstract

This study investigates the performance of static Precise Point Positioning (PPP) as a function of fixing duration using the magic-GNSS free online service. The platform supports processing of GPS-only, GLONASS-only, and combined GPS+GLONASS observations, enabling a direct comparison between individual and integrated satellite systems. The evaluation was conducted under open-sky conditions to minimize multipath effects. Dual-frequency GNSS observations were collected from ten well-distributed stations, each with a continuous 24-hour observation session. Static PPP solutions were generated for fixing intervals starting from 1 hour and progressively increasing up to 24 hours. The 24-hour solution was adopted as the reference to assess the accuracy of shorter observation durations. The results reveal that the GPS-only and GPS+GLONASS solutions are identical, indicating that the magic-GNSS processing strategy relies primarily on GPS observations when they are available. In contrast, GLONASS-only results demonstrate superior performance during short observation periods. Within the first hour, GLONASS achieves lower average absolute errors than GPS by approximately 1.5 cm, 2 cm, 2 cm, 2 cm, and 3 cm in the Easting, Northing, Height, 2D, and 3D components, respectively. The 1 cm accuracy level in the horizontal plane is reached after approximately 7.5 hours using GPS-only observations, compared to only 3 hours using GLONASS-only. For the height component, the same accuracy level is achieved after 7.5 hours and 4 hours, respectively. Furthermore, both systems converge to millimeter-level accuracy with longer observation durations. In the horizontal components, GPS and GLONASS reach approximately 1 mm accuracy after 15 hours and 6 hours, respectively, while in the vertical component, this level is achieved after approximately 14 hours for GPS and 15 hours for GLONASS. These findings confirm that both GPS-only and GLONASS-only PPP can deliver accurate and reliable positioning under open-sky conditions when sufficient observation time and precise ephemerides are used. However, GLONASS-only observations exhibit significantly faster convergence, reaching centimeter-level accuracy in both horizontal and vertical components in a shorter time compared to GPS-only.

Keywords: GPS; Precise Point Positioning; magic-GNSS; Static Positioning; Fixing Time

1. Introduction

Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS), are space-based positioning infrastructures that enable the determination of position and velocity through passive ranging observations [1]. The two systems operate continuously and independently of weather conditions [2], providing precise real-time positioning and timing services on a global scale [3]. These systems rely on satellite constellations that broadcast signals on two principal frequencies, modulated using Coarse/Acquisition (C/A) and Precise (P) codes [4]. From these signals, GNSS receivers derive pseudo-range and carrier-phase measurements, which form the foundation of modern navigation, mapping, and geodetic applications [5]. The achievable positioning accuracy depends on several factors, including satellite geometry, atmospheric effects, and receiver characteristics [6]. The two systems are different in number of orbital planes, altitude, number of satellites, inclination angles, and frequency as illustrated in the table below.

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Table 1 Comparison Between GPS and GLONASS

Feature	GPS	GLONASS
Full Constellation	~31 satellites	~24 satellites
Orbital Planes	6	3
Orbit Altitude	~20,200 km	~19,100 km
Inclination Angle	55°	64.8°
Frequencies	L1, L2, L5	L1, L2, L3
Time Reference	GPS Time	GLONASS Time (UTC-based)
Coordinate System	WGS84	PZ-90
Global Coverage	Excellent	Excellent (better at high latitudes)
Accuracy (Standalone)	High	Comparable (varies with geometry)
Strengths	Stable, widely used, strong global infrastructure	Better performance at high latitudes, faster geometry variation
Weaknesses	Slightly weaker geometry at high latitudes	Frequency-dependent biases, less common in older receivers

Positioning techniques based primarily on code measurements typically provide meter-level accuracy [7,8], which is sufficient for applications with moderate precision requirements, such as ground vehicle navigation [9], unmanned aerial vehicle (UAV) operations [10], and the generation of low-accuracy ortho-mosaics and digital elevation models [11]. In contrast, high-precision applications, including geodetic control, deformation monitoring, and precision engineering, require centimeter-level accuracy [12]. Such performance can be achieved using advanced processing techniques, notably Differential GNSS (DGNSS) and Precise Point Positioning (PPP) [13].

DGNSS enhances positioning accuracy by combining simultaneous observations from a reference station with known coordinates and a rover receiver at an unknown location [14]. The use of single-, double-, or triple-differenced observations effectively reduces common error sources, such as satellite clock biases and ionospheric delays [15]. Dual-frequency DGNSS systems can achieve millimeter-level accuracy, while single-frequency systems typically provide decimeter-level precision at lower cost. However, the requirement for a nearby reference station limits the applicability of DGNSS, particularly in large-scale or remote regions [16].

Precise Point Positioning (PPP) provides a globally applicable technique that enables high-accuracy positioning without the need for local reference stations [17]. It relies on precise satellite orbit and clock products, typically provided by the International GNSS Service (IGS), combined with rigorous modeling of atmospheric, relativistic, and geophysical effects [18]. Under favorable conditions, PPP can achieve centimeter-level accuracy in both static and kinematic modes; however, it generally requires longer convergence times compared to Differential GNSS (DGNSS) [19]. Among available online PPP processing platforms, the magic-GNSS free service is widely utilized, supporting GPS-only, GLONASS-only, and combined GPS+GLONASS configurations, and providing coordinate solutions referenced to various datums. Users can upload dual-frequency RINEX observation files, after which the service automatically applies precise ephemerides, clock corrections, and atmospheric models to generate final positioning solutions. The performance of PPP is influenced by several factors, including satellite availability and geometry, multipath effects, antenna characteristics [20], atmospheric modeling [21], and the quality of precise orbit and clock products (ultra-rapid, rapid, or final) [22,23]].

In this study, the performance of static PPP is evaluated using the magic-GNSS service with final precise ephemerides under open-sky conditions to minimize multipath effects. Dual-frequency observations were collected from ten well-distributed stations, each observed continuously for 24 hours. Data were processed in static mode using GPS-only, GLONASS-only, and combined GPS+GLONASS configurations. The 24-hour solutions were adopted as reference coordinates to assess the accuracy of shorter observation durations. Despite extensive research on PPP, further investigation remains necessary. Many previous studies do not fully isolate the impact of multipath, and PPP accuracy is often assessed using DGNSS-derived coordinates, which may themselves be affected by multipath, weak satellite geometry, long baselines, or height differences between reference and rover stations. Moreover, continuous advancements in GNSS constellations and processing strategies necessitate regular re-evaluation of positioning techniques. This study forms part of ongoing efforts at the University of Benghazi to evaluate widely used free PPP online services in both static and kinematic modes, including CSRS-PPP [16,17], PPP-WIZARD [18,19], APPS [20,21], and Qinertia Cloud [14,15]. Future work will extend this research to multipath-rich environments, as well as to the integration of PPP with MEMS-based inertial navigation systems and vision-based navigation techniques. Additional efforts will also focus on improving PPP performance for drone-based surveying to reduce processing time in automated image-matching workflows. Related studies conducted at the University of Benghazi are presented in [24-28].

The data used in this investigation were obtained from multiple projects conducted across Libya through the Engineering Consultancy Office of the University of Benghazi. Ten independent datasets were collected using a dual-frequency GNSS receiver operating in static mode under clear, unobstructed desert conditions, with each observation lasting 24 hours. All datasets were initially processed using a GPS-only configuration, with observation durations ranging from 1 hour to 24 hours. The 24-hour PPP solution was adopted as the reference benchmark. For each observation interval, the corresponding PPP-derived coordinates were compared with the reference solution to compute absolute positioning errors in the Easting, Northing, Height, two-dimensional (E+N), and three-dimensional (E+N+H) components. The results from the ten stations were then statistically analyzed to identify and remove outliers and to derive final positioning accuracy metrics. The use of spatially distributed datasets across Libya enabled an assessment of the effects of satellite visibility and geographic distribution on PPP accuracy and solution stability.

2. Results and Discussion

The average absolute errors of E, N, H, 2D and 3D absolute differences in GPS-alone are shown in figures (1), (2), (3), (4) and (5), respectively.

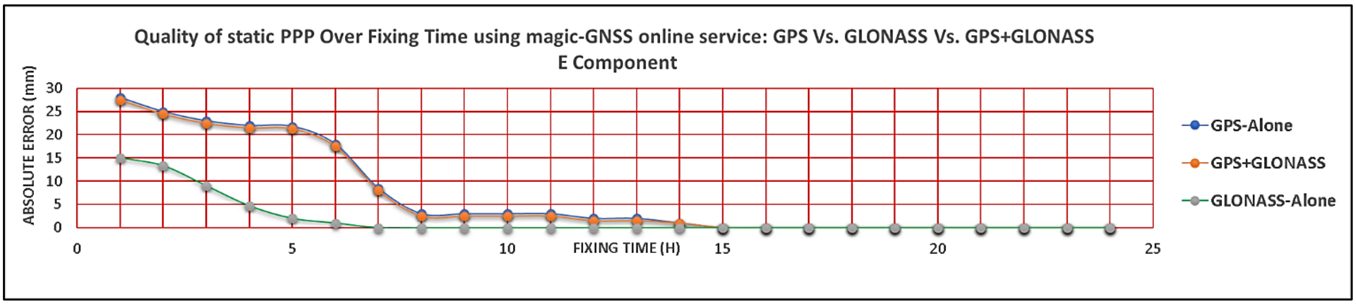

Figure 1 Static PPP using magic-GNSS: Easting Component: GPS Vs. GLONASS Vs. GPS+GLONASS

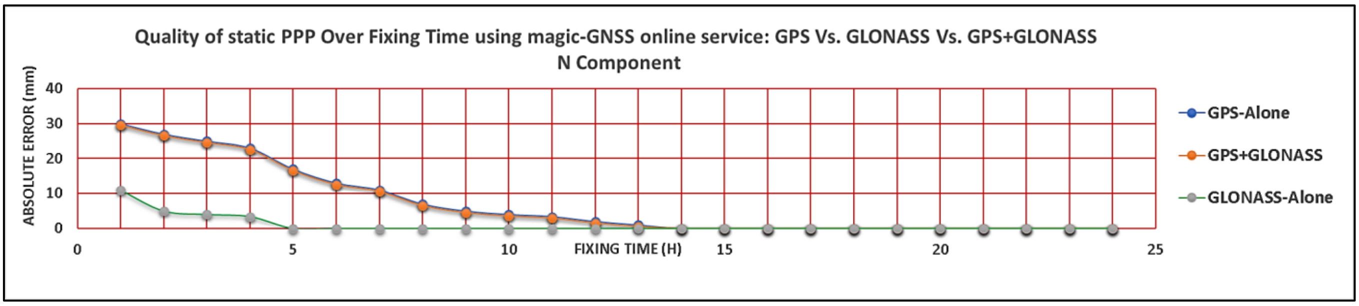

Figure 2 Static PPP using magic-GNSS: Northing Component: GPS Vs. GLONASS Vs. GPS+GLONASS

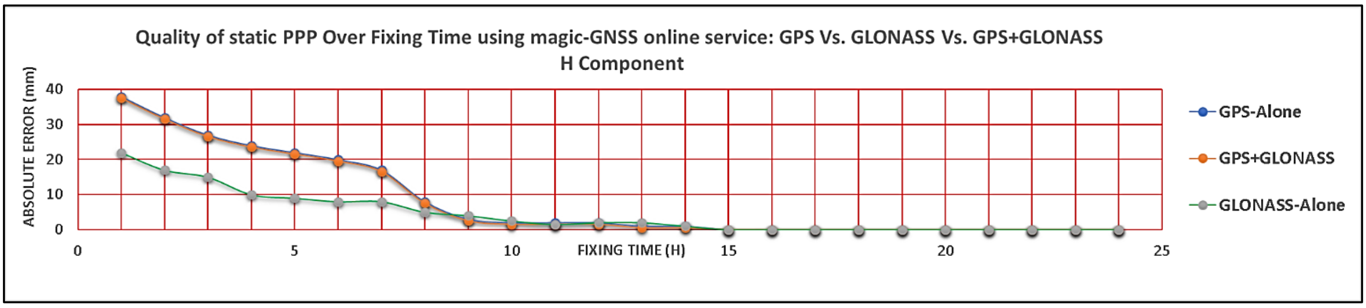

Figure 3 Static PPP using magic-GNSS: Height Component: GPS Vs. GLONASS Vs. GPS+GLONASS

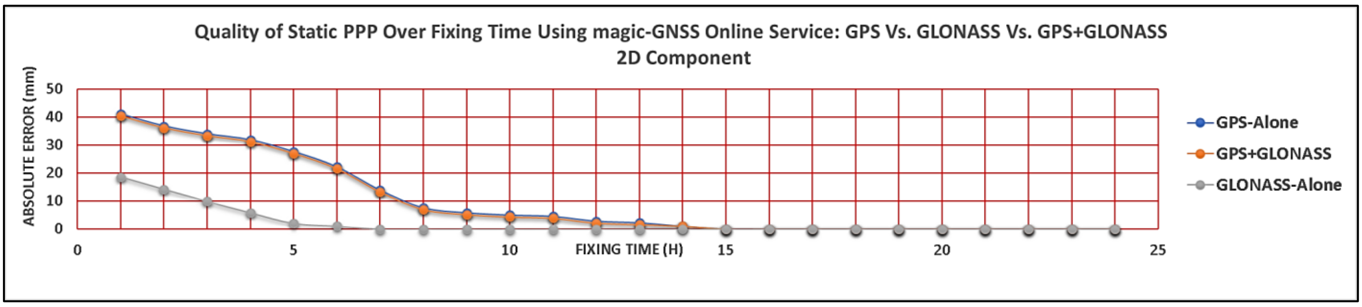

Figure 4 Static PPP using magic-GNSS: 2D Component: GPS Vs. GLONASS Vs. GPS+GLONASS

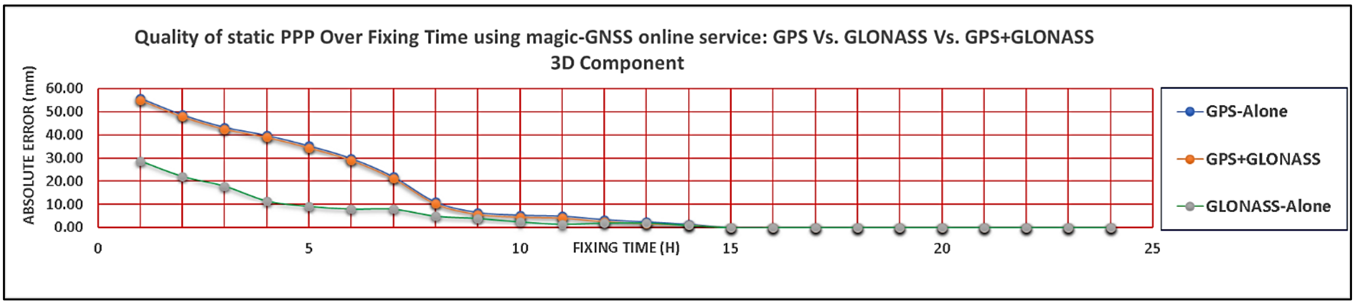

Figure 5 Static PPP using magic-GNSS: Easting Component: GPS Vs. GLONASS Vs. GPS+GLONASS

The results demonstrate that GPS-alone and GPS+GLONASS solutions are practically identical, indicating that the magic-GNSS processing strategy prioritizes GPS observations when available, with limited contribution from GLONASS in the combined solution. In contrast, the GLONASS-alone solution exhibits superior performance during short observation periods, highlighting its advantage in the early stages of PPP convergence. This behavior is primarily attributed to the higher orbital inclination of GLONASS satellites (~64.8°), which enhances satellite visibility and strengthens the observation geometry, particularly in the north–south direction.

Quantitatively, during the first hour, GLONASS outperforms GPS with lower average absolute errors of approximately 1.5 cm in Easting, 2 cm in Northing, 2 cm in Height, 2 cm in 2D, and 3 cm in 3D positioning. This indicates a more efficient ambiguity convergence and faster stabilization of the PPP solution. The horizontal 1 cm accuracy threshold is achieved after approximately 3 hours using GLONASS observations, compared to about 7.5 hours for GPS processing. Similarly, in the vertical component, GLONASS reaches this level after approximately 4 hours, while GPS requires about 7.5 hours. These differences confirm that GLONASS provides a clear advantage in reducing PPP convergence time. With increasing observation duration, the performance gap between the two systems diminishes, and both solutions converge toward millimeter-level accuracy. In the horizontal components, GLONASS achieves ~1 mm accuracy after approximately 6 hours, whereas GPS requires about 13 hours. In the vertical component, both systems reach comparable millimeter-level accuracy after approximately 14–15 hours, indicating that long observation sessions effectively mitigate initial geometric and convergence limitations.

The observed improvement in accuracy with time is consistent with PPP theory, where the accumulation of observations enhances solution robustness. Increased redundancy in the adjustment model allows for more reliable estimation of parameters and facilitates the detection and exclusion of observations with large residuals. Furthermore, extended observation periods reduce the dependency on low-elevation satellites, whose measurements are more susceptible to atmospheric delays and multipath effects. As a result, the overall solution becomes progressively less sensitive to initial satellite geometry and stochastic errors. A notable outcome is the superior performance of GLONASS in the Northing component, which can be directly linked to its higher orbital inclination and the resulting improvement in satellite distribution along the north–south axis. This enhanced geometric strength leads to more precise estimation in this direction compared to GPS, as illustrated in Figure 6.

Overall, these findings confirm that both GPS and GLONASS PPP solutions are capable of delivering high-accuracy positioning under open-sky conditions when sufficient observation time and high-quality precise products are used. However, GLONASS demonstrates a clear advantage in terms of convergence speed, achieving centimeter-level accuracy significantly faster than GPS. This characteristic makes GLONASS particularly beneficial in applications where reduced observation time is critical, such as rapid static surveys and time-constrained field operations.

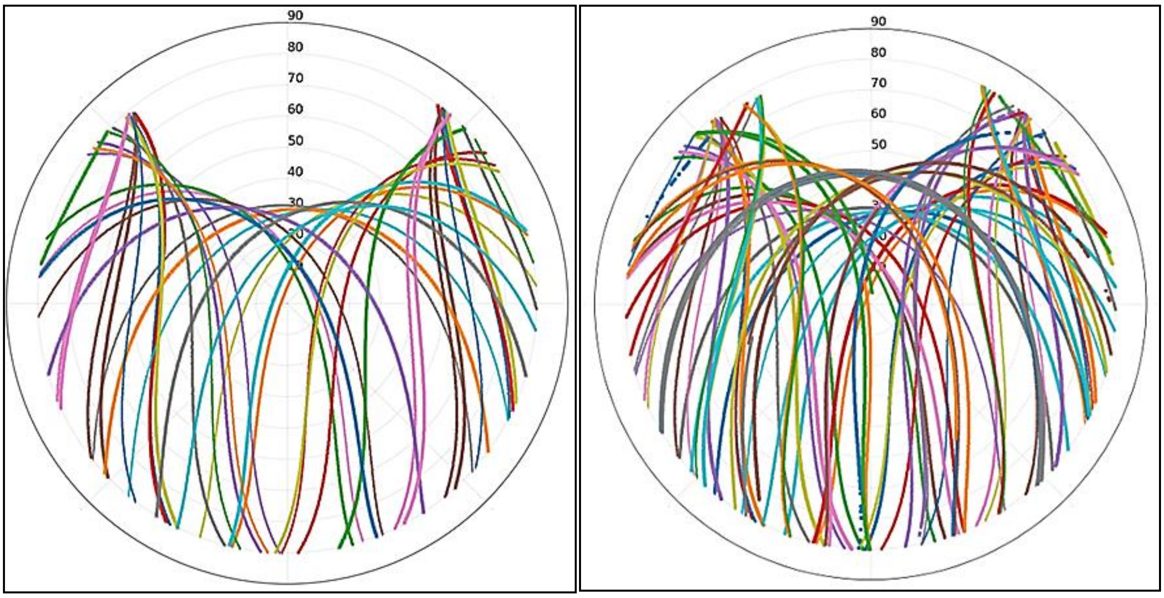

Figure 6 Satellite Sky Distribution: GPS-alone (left) Vs. GPS+GLONASS (right)

3. Conclusion

This study evaluated the performance of static Precise Point Positioning (PPP) using the magic-GNSS free online service under open-sky conditions, with a particular focus on the effect of observation duration and GNSS constellation configuration. The results demonstrate that both GPS-alone and GLONASS-alone PPP solutions are capable of achieving high positioning accuracy when sufficient observation time and final precise ephemerides are employed. However, clear differences in convergence behavior were observed between the two systems. GLONASS-alone processing consistently exhibited faster convergence, achieving centimeter-level accuracy in significantly shorter observation times compared to GPS-alone solutions. This advantage is primarily attributed to the higher orbital inclination of GLONASS satellites, which improves satellite geometry, particularly in the north–south direction, and enhances early-stage solution stability. In contrast, GPS-alone solutions require longer observation periods to reach comparable accuracy levels, although both systems ultimately converge to millimeter-level precision under extended observation durations. The combined GPS+GLONASS solution showed no significant improvement over GPS-alone results, indicating that the processing strategy of the magic-GNSS service predominantly relies on GPS observations when available. This highlights a potential limitation in fully exploiting multi-constellation benefits within the employed processing framework. Overall, the findings confirm that PPP performance strongly depends on observation duration, satellite geometry, and constellation characteristics. While long observation sessions mitigate most limitations and yield highly precise results, GLONASS offers a distinct advantage for applications requiring rapid convergence. These results provide practical guidance for optimizing PPP-based surveying strategies, particularly in time-constrained scenarios.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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