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Static PPP Over Observation Time: Magic-GNSS Vs. Qinertia Cloud

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Abstract

This study presents a comparative evaluation of static Precise Point Positioning (PPP) performance as a function of fixing duration using two free online processing services, namely magic-GNSS and Qinertia Cloud. The analysis considers different constellation configurations, including GPS-only, GLONASS-only, and combined GPS+GLONASS, under ideal open-sky conditions to eliminate multipath effects and isolate the impact of satellite geometry and processing strategies. Dual-frequency GNSS observations from ten well-distributed stations, each with 24-hour datasets, were processed using fixing intervals ranging from 1 to 24 hours, with the fully converged 24-hour solution adopted as the reference benchmark. The results reveal notable differences between the two platforms in terms of constellation utilization and performance. In the magic-GNSS solution, GPS-only and GPS+GLONASS results are effectively identical, indicating that the processing strategy relies primarily on GPS observations when available. In contrast, GLONASS-only observations exhibit significantly faster convergence, outperforming GPS during short observation periods. Within the first hour, GLONASS achieves lower average absolute errors than GPS by approximately 1.5–3 cm across position components and reaches the 1 cm accuracy level after about 3–4 hours, compared to approximately 7.5 hours for GPS. Millimeter-level accuracy is achieved by both systems with longer observation durations, although GLONASS demonstrates faster horizontal convergence. Conversely, the Qinertia Cloud results confirm the advantage of multi-constellation integration, where the combination of GPS+GLONASS consistently improves solution robustness and stability compared to GPS-only. The enhancement is most pronounced during the early convergence stage, with error reductions of approximately 2–4 cm across all components within the first hour. While the accuracy improvement becomes less significant over longer durations, the inclusion of GLONASS effectively reduces solution dispersion and mitigates outliers, leading to more stable positioning results. Overall, the findings highlight that PPP performance is strongly influenced by both the processing strategy and constellation configuration. While magic-GNSS emphasizes GPS dominance with limited benefit from integration, Qinertia Cloud demonstrates clear advantages of multi-constellation processing. Despite these differences, both studies agree that integrating GLONASS or using it independently significantly enhances convergence speed, particularly during short observation periods, while long-duration observations enable all configurations to achieve centimeter- to millimeter-level accuracy.

Keywords: GPS; Precise Point Positioning; Magic-GNSS; Qinertia Cloud; 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].

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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.

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 and Qinertia Cloud free services are widely utilized, providing coordinate solutions referenced to various datums supporting. Both services support GPS-only and combined GPS+GLONASS configurations, and magic-GNSS overcomes the other in terms of supporting GLONASS-only. Users can upload dual-frequency RINEX observation files, after which the services automatically apply 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 as well as Qinertia Cloud services 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, combined GPS+GLONASS, and GLONASS-only configurations for magic-GNSS. 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], magic-GNSS [24], 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 [25-29].

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 are shown in figures 1 to 5 for magic-GNSS, and 6 to 10 for Inertia Cloud, respectively.

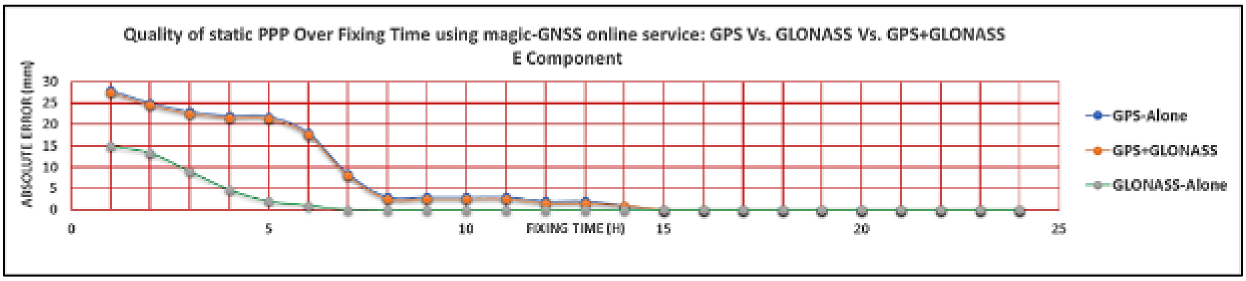

Figure 1 Static PPP using magic-GNSS: Easting Component: GPS Vs. GLONASS Vs. GPS+GLONASS

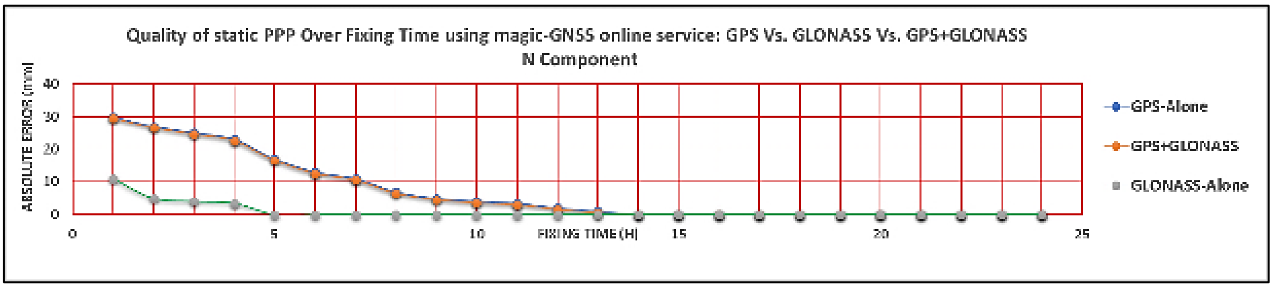

Figure 2 Static PPP using magic-GNSS: Northing Component: GPS Vs. GLONASS Vs. GPS+GLONASS

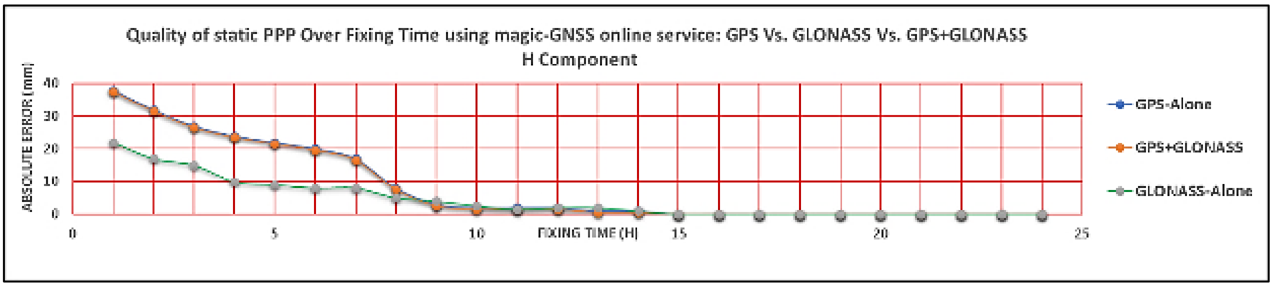

Figure 3 Static PPP using magic-GNSS: Height Component: GPS Vs. GLONASS Vs. GPS+GLONASS

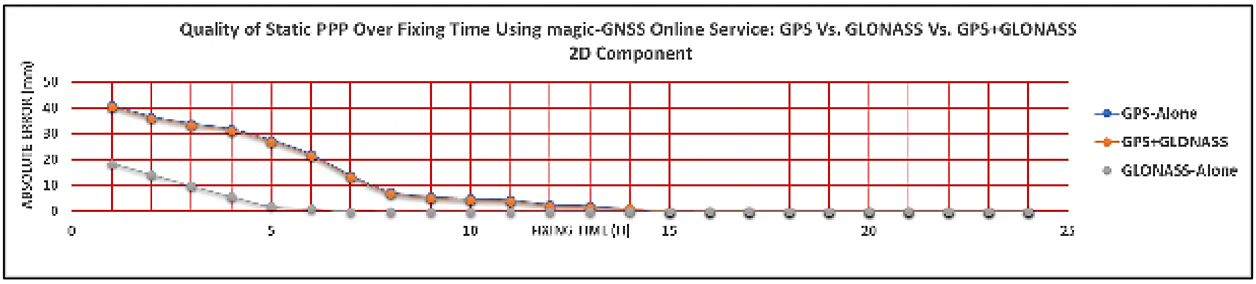

Figure 4 Static PPP using magic-GNSS: 2D Component: GPS Vs. GLONASS Vs. GPS+GLONASS

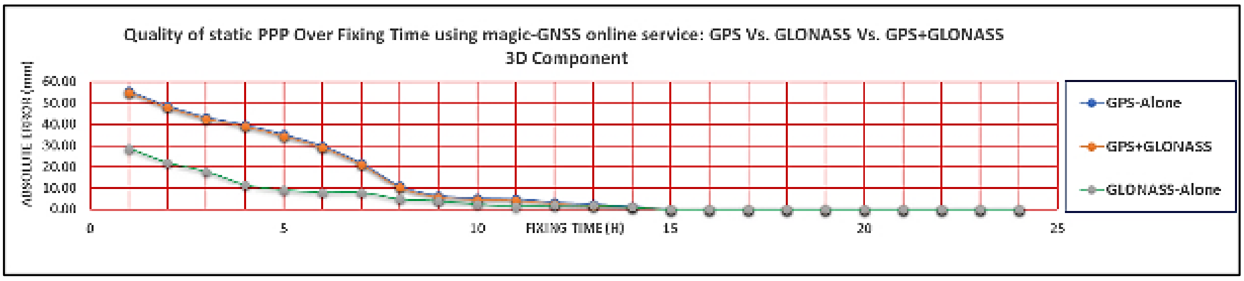

Figure 5 Static PPP using magic-GNSS: 3D Component: GPS Vs. GLONASS Vs. GPS+GLONASS

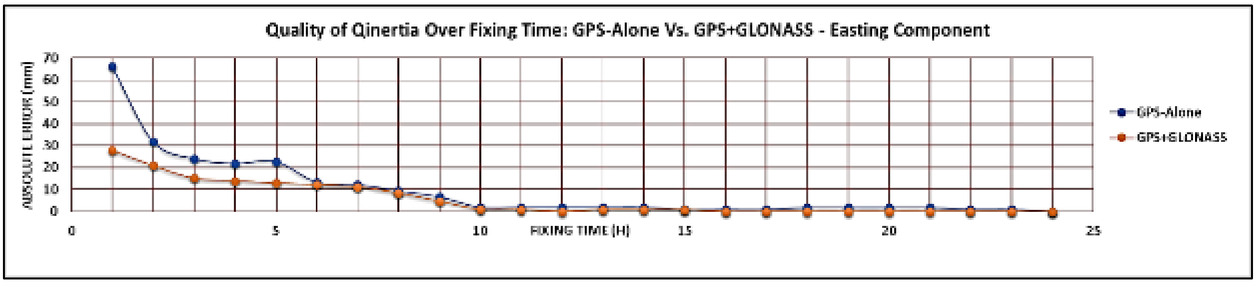

Figure 6 Static PPP using Qinertia Cloud: Easting Component: GPS Vs. GPS+GLONASS

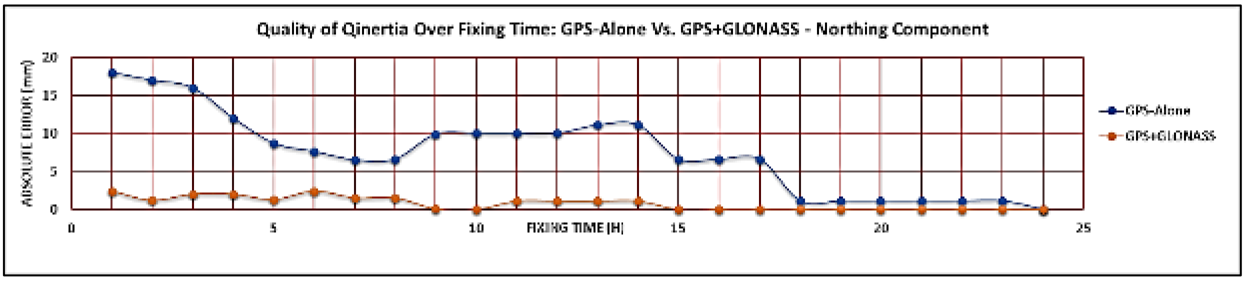

Figure 7 Static PPP using Qinertia Cloud: Northing Component: GPS Vs. GPS+GLONASS

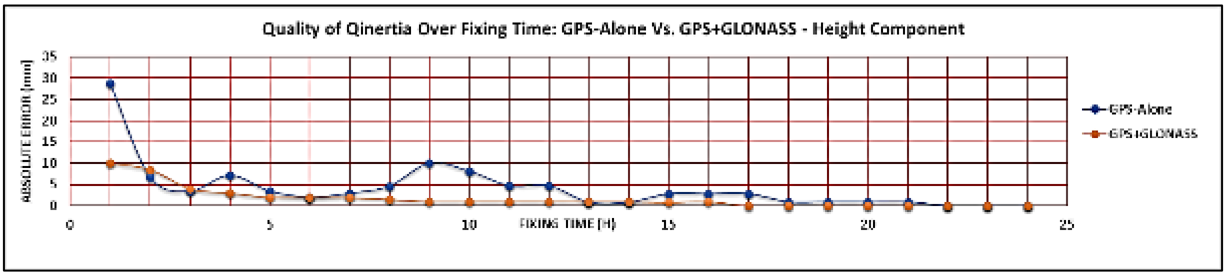

Figure 8 Static PPP using Qinertia Cloud: Height Component: GPS Vs. GPS+GLONASS

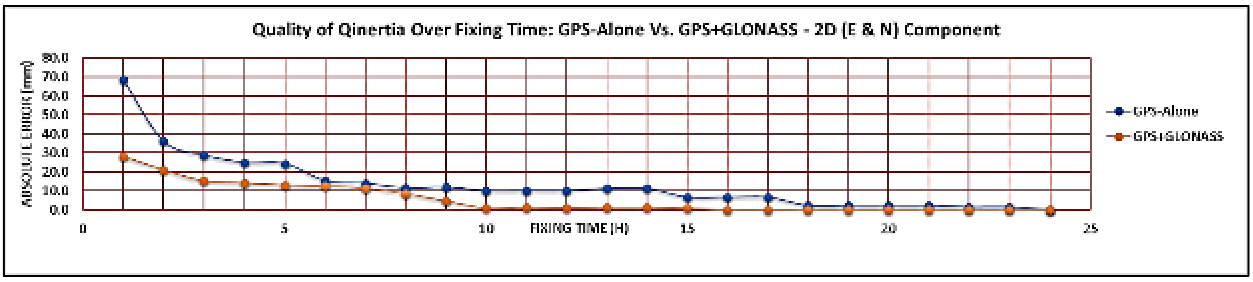

Figure 9 Static PPP using Qinertia Cloud: 2D Component: GPS Vs. GPS+GLONASS

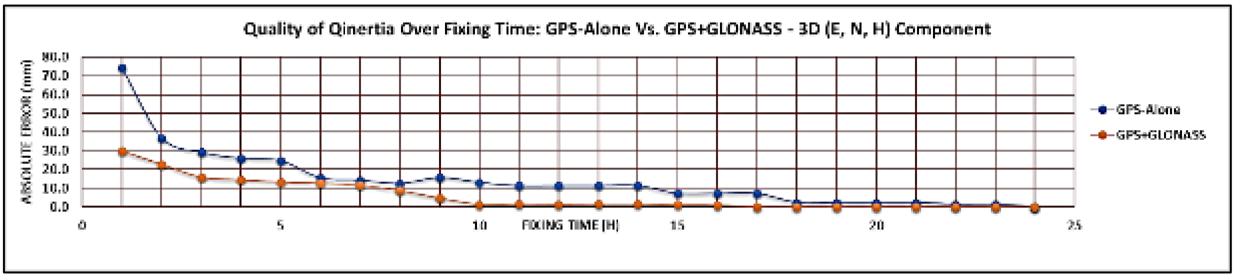

Figure 10 Static PPP using Qinertia Cloud: 3D Component: GPS Vs. GPS+GLONASS

A direct comparison between the results obtained from magic-GNSS and Qinertia Cloud reveals that PPP performance is not governed solely by constellation characteristics, but is strongly influenced by the underlying processing strategy adopted by each service. Although both analyses were conducted under identical open-sky conditions and using comparable datasets, the behavior of GPS, GLONASS, and their integration differs markedly between the two platforms, leading to distinct interpretations of multi-constellation benefits.

In the case of magic-GNSS, the results indicate that GPS-only and GPS+GLONASS solutions are practically indistinguishable, suggesting that the processing engine prioritizes GPS observations and assigns limited effective weight to GLONASS when both are available. This behavior masks the potential advantages of multi-constellation integration and shifts the focus toward evaluating each system independently. Within this framework, GLONASS-only observations demonstrate a clear superiority during the early stages of PPP convergence. This advantage 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. Consequently, during the first hour, GLONASS achieves lower average absolute errors than GPS by approximately 1.5 cm (E), 2 cm (N), 2 cm (H), 2 cm (2D), and 3 cm (3D), reflecting a more efficient ambiguity resolution and faster stabilization of the solution.

This faster convergence is further confirmed by the time required to reach the 1 cm accuracy threshold, which is achieved after approximately 3–4 hours using GLONASS, compared to about 7.5 hours for GPS. Moreover, GLONASS attains millimeter-level accuracy in the horizontal components after approximately 6 hours, whereas GPS requires more than double this duration. The superior performance in the Northing component is particularly notable and can be directly linked to the improved north–south satellite distribution due to higher orbital inclination. However, as observation time increases, the performance gap between the two systems gradually diminishes, with both converging to comparable millimeter-level accuracy after approximately 14–15 hours. This trend aligns with PPP theory, where extended observation periods enhance redundancy, improve parameter estimation, and reduce the impact of initial geometric limitations and stochastic errors.

In contrast, Qinertia Cloud demonstrates a fundamentally different behavior, where the integration of GLONASS with GPS produces consistent and measurable improvements across all observation durations. Unlike magic-GNSS, the combined GPS+GLONASS solution in Qinertia fully exploits the additional observations, leading to enhanced geometric strength, improved redundancy, and greater robustness. The most significant improvements are observed during the early convergence phase, where PPP solutions are inherently sensitive to satellite geometry. Within the first hour, the GPS+GLONASS configuration reduces positioning errors from (6.8, 1.5, 2.8, 7, 7.4 cm) to (2.8, 0.25, 1, 2.8, 3 cm) in the E, N, H, 2D, and 3D components, respectively, demonstrating a substantial enhancement in both accuracy and stability.

Furthermore, Qinertia results highlight that multi-constellation integration not only improves mean accuracy but also reduces the dispersion of residuals and mitigates outliers, even under ideal observational conditions. The improvement in the Northing component is again linked to the higher inclination of GLONASS satellites, which compensates for the geometric imbalance typically observed in GPS-only configurations. Additionally, the strong performance in the vertical component, particularly achieving about 1 cm accuracy within the first hour for GPS+GLONASS, can be attributed to effective stochastic modeling and the exclusion of low-elevation observations, which reduces noise and multipath effects while maintaining acceptable geometric strength.

When comparing both services, a key insight emerges: while magic-GNSS highlights the intrinsic capability of GLONASS as a standalone system, particularly in accelerating PPP convergence, Qinertia Cloud demonstrates the practical advantages of integrating multiple constellations within a well-optimized processing framework. In other words, the superiority of GLONASS observed in magic-GNSS during short observation periods is effectively translated, in Qinertia, into a combined solution that outperforms GPS-only processing in both accuracy and robustness. This indicates that the benefits of GLONASS are not merely constellation-dependent, but are highly contingent on how observations are weighted, modeled, and integrated within the PPP algorithm.

Overall, both studies converge toward a consistent conclusion: the primary benefit of GLONASS lies in enhancing convergence speed and improving solution stability during short observation durations. However, the extent to which this benefit is realized depends critically on the processing strategy. While long observation sessions (beyond ~12–15 hours) reduce these differences and allow all configurations to achieve millimeter-level accuracy, the choice of processing service and constellation integration becomes decisive for time-constrained applications. In this context, Qinertia Cloud demonstrates a more effective utilization of multi-constellation observations, whereas magic-GNSS provides clearer insight into the individual performance characteristics of each GNSS system.

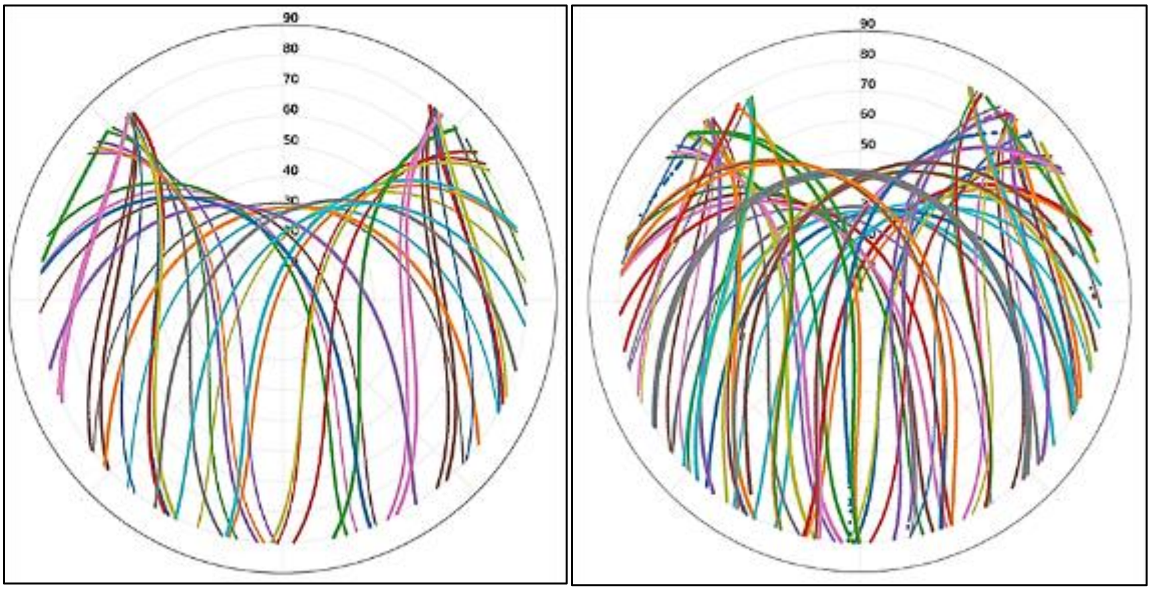

Figure 11 Satellite Sky Distribution: GPS-alone (left) Vs. GPS+GLONASS (right)

3. Conclusion

This study presented a comprehensive evaluation of static Precise Point Positioning (PPP) performance as a function of observation duration using two free online processing services, magic-GNSS and Qinertia Cloud, with emphasis on GPS-only, GLONASS-only, and combined GPS+GLONASS configurations. The results demonstrate that PPP accuracy and convergence behavior are not only dependent on satellite constellation characteristics, but are also strongly influenced by the adopted processing strategy.

The findings from magic-GNSS reveal that GLONASS, when used independently, provides significantly faster convergence compared to GPS, achieving centimeter-level accuracy within substantially shorter observation times. This advantage is primarily attributed to its higher orbital inclination and the resulting improvement in satellite geometry, particularly in the north–south direction. However, the absence of noticeable improvement in the combined GPS+GLONASS solution indicates limited utilization of GLONASS observations within the processing framework.

In contrast, Inertia Cloud effectively exploits multi-constellation integration, where the combination of GPS and GLONASS consistently enhances positioning accuracy, robustness, and solution stability. The improvement is most evident during the early convergence phase, where the GPS+GLONASS solution significantly reduces positioning errors and achieves accuracy levels comparable to several hours of GPS-only observations. Additionally, multi-constellation processing contributes to reducing residual dispersion and mitigating outliers, even under ideal open-sky conditions.

A key outcome of this study is that the benefit of GLONASS is twofold: it can either act as a strong standalone system that accelerates PPP convergence, as observed in magic-GNSS, or as a complementary constellation that enhances overall solution quality when properly integrated, as demonstrated by Inertia Cloud. Nevertheless, for long observation durations, all configurations converge toward similar centimeter- to millimeter-level accuracy, indicating that extended observation time can compensate for initial geometric and modeling limitations.

Overall, this study highlights that the optimal PPP performance is achieved through effective multi-constellation integration combined with robust processing strategies. For time-constrained applications, such as rapid static surveys, the use of GPS+GLONASS within an optimized processing environment is strongly recommended. These findings emphasize the critical role of processing algorithms in fully exploiting GNSS capabilities and provide practical guidance for selecting appropriate PPP solutions based on operational requirements.

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