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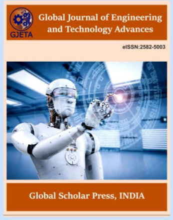

(Research Article)

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Dual-Frequency Static PPP Over Fixing Time Using Final-Product Free Online Services: CSRS-PPP Vs. PPP-WIZARD Vs. APPS

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Abstract

This study examines the performance of dual-frequency static Precise Point Positioning (PPP) as a function of observation time using three of the most used free online services, namely: the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP), PPP-WIZARD, and the Automatic Precise Positioning Service (APPS). The comparison has been conducted under open-sky desert conditions, where multipath effects are negligible, and under two processing scenarios: GPS-only and GPS+GLONASS in case of CSRS-PPP & PPP-WIZARD, and GPS-alone in case of APPS. Dual-frequency GNSS data has been collected from ten spatially well-distributed stations across Libya, each observed continuously for 24 hours. Static PPP solutions have been generated for fixing intervals beginning at 1 hour and incrementally increasing to 24 hours. The coordinates of these reference points, provided and approved by Libyan Survey Authority, have been used as the reference for evaluating the accuracy and stability of all time-based solutions. In terms of comparing GPS + GLONASS with GPS-alone, the results of PPP-CSRS & PPP-WIZARD services show that even under optimal open-sky conditions, where multipath is virtually absent and the number of satellite is adequate, utilizing GLONASS observations alongside GPS leads to notable improvements in solution reliability, robustness and overall positioning stability throughout the fixing intervals. These benefits are particularly clear during the first several hours, when PPP solutions are most sensitive to satellite geometry and convergence behavior. This can be shown significantly in the first hour, where the absolute errors in Easting (E), Northing (N), Height (H), 2 Dimensions (2D), and 3 Dimensions (3D) are reduced with GPS+GLONASS by (0.2, 2.2, 3, 1.8 and 2.22 cm) & (6, 6.5, 11, 9, and 13 cm) for PPP-CSRS & PPP-WIZARD, respectively. In addition, although the enhancement in mean absolute positional accuracy becomes marginal for longer observation periods, the multi-constellation configuration significantly reduces the occurrence of outliers and decreases the dispersion of coordinate residuals across all components and the 3D quality obtained via one-hour static dual-frequency PPP with GPS+GLONASS can be reached after 3 to 4 hours fixing time using GPS-alone. As for comparing the performance of the three free online services together, CSRS-PPP ranks first and second, as it has provided the most accurate results and the fastest convergency time, with 3D absolute error of nearly 2 cm & 5 cm for GPS+GLONASS and GPS-alone solutions, respectively after only one hour fixing time. The quality of these two solutions increases with time, reaching the level of less than 1 cm after 6 and 10 hours using multi constellations and GPS-alone, respectively. PPP-WIZARD comes third and fourth, with comparable 3D quality of 7 cm for GPS+GLONASS and acceptable 3D quality of 20 cm for GPS-alone after one hour fixing time. The results show that the quality of the two PPP-WIZARD solutions may not be able to reach the level of 1 cm even after 24 hours observation period. The APPS GPS-alone solution comes last in term of the 3D quality of the first fixing hour with accuracy of 45 cm, but the performance improves quickly comparing to PPP-WIZARD GPS-alone solution and almost matches that of PPP-WIZARD GPS+GLONASS for long period before reaching the level of 1 cm after nearly 20 hours of fixing time. Overall, the findings confirm that multi-constellation GNSS integration is a critical factor in enhancing static PPP performance, particularly for applications requiring high accuracy over short observation periods. Among the investigated services, CSRS-PPP is identified as the most reliable and efficient solution, while PPP-WIZARD and APPS remain viable alternatives for longer observation durations.

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Keywords: GPS; GLONASS; PPP; CSRS-PPP; PPP-WIZARD; APPS; Static Positioning; Fixing Time

1. Introduction

Global Navigation Satellite Systems (GNSS), including the Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS), are space-based positioning infrastructures that enable the determination of instantaneous position and velocity through passive ranging observations [1]. GNSS operate continuously under all weather conditions and provide accurate real-time positioning and timing services on a global scale [2]. These systems rely on satellite constellations that transmit signals on two main frequencies, modulated using Coarse/Acquisition (C/A) and Precise (P) codes [3]. Based on these signals, GNSS receivers generate pseudo-range and carrier-phase observations, which constitute the fundamental measurements for modern navigation, mapping, and geodetic applications [4]. The positioning accuracy achievable with GNSS is influenced by several factors, including satellite geometry, atmospheric propagation effects, and receiver-related characteristics [5]. Positioning approaches that primarily depend on code-based measurements generally provide meter-level accuracy, which is adequate for applications with moderate precision requirements, such as ground vehicle navigation [6], unmanned aerial vehicle (UAV) operations [7], and the generation of low-accuracy ortho-mosaic products and digital elevation models [8]. Conversely, high-precision applications, including geodetic control networks, deformation monitoring, and precision engineering, require centimeter-level accuracy [9]. Such performance can be achieved through advanced processing techniques, most notably Differential GNSS (DGNSS) and Precise Point Positioning (PPP) [10].

DGNSS enhances positioning accuracy by combining simultaneous observations from a reference station with known coordinates and a rover receiver at an unknown location [11]. The use of single, double, or triple-differenced observations effectively reduces common error sources, such as satellite clock offsets and ionospheric delays [12,13]. Dual-frequency DGNSS systems are capable of attaining millimeter-level accuracy, whereas single-frequency implementations typically achieve decimeter-level precision at a significantly lower cost [14]. Despite its high accuracy, DGNSS applicability is constrained by the requirement for a nearby reference station, limiting its effectiveness in large-scale or remote regions [15]. In contrast, PPP offers a globally applicable alternative that delivers high accuracy without the need for a local reference station. PPP utilizes precise satellite orbit and clock products, typically provided by the International GNSS Service (IGS), in conjunction with advanced atmospheric and relativistic error modeling. PPP is capable of achieving centimeter-level accuracy in both static and kinematic modes, although it generally requires longer convergence times compared to DGNSS [16].

This study evaluates three widely used free online PPP processing services: the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service, PPP-WIZARD, and the Automatic Precise Positioning Service (APPS). CSRS-PPP, developed by Natural Resources Canada (NRCan), supports both static and kinematic GNSS data processing and provides coordinate solutions referenced to the International Terrestrial Reference Frame (ITRF) [9,10]. PPP-WIZARD is a zero-difference PPP ambiguity-resolution technique developed by the French governmental space agency CNES; it supports both static and kinematic GNSS datasets and outputs coordinate solutions referenced to the International Terrestrial Reference Frame (ITRF2020) [11,15]. APPS processes GPS-alone observation files and applies advanced GPS PPP algorithms developed by the NASA Jet Propulsion Laboratory. It supports both static and kinematic datasets and provides coordinate solutions referenced to the GRS80 geodetic reference frame [14,16]. For all three services, users upload dual-frequency GNSS RINEX files, after which precise satellite ephemerides, clock corrections, and atmospheric models are automatically applied to generate high-quality positioning solutions. PPP performance is affected by several factors, including the number of tracked satellites, the surrounding multipath environment, satellite constellation availability, GNSS antenna type and quality [17], ionospheric and tropospheric delay modeling, and the type of precise orbit products used (ultra-rapid, rapid, or final) [16].

The primary objective of this study is to evaluate the quality of static PPP solutions as a function of fixing time using the CSRS-PPP, PPP-WIZARD, and APPS free online services with dual-frequency observations collected under genuine open-sky conditions and processed using final precise products. In addition, the study investigates the impact of integrating GLONASS observations with GPS in static PPP solutions for the CSRS-PPP and PPP-WIZARD services. This investigation is motivated by the fact that most previous studies have emphasized PPP accuracy at full convergence, rather than examining the evolution of accuracy at incremental hourly intervals. Also, the many previous efforts concentrate on the individual evaluation of these services, which may not enough for providing a clear view about the performance of each service comparing to the others. Further research is therefore warranted, as much of the existing literature assesses static PPP performance without fully isolating the influence of multipath effects. Moreover, many studies evaluate PPP accuracy by comparison with DGNSS-derived coordinates obtained from real-time or post-processed solutions, which may introduce additional uncertainty due to multipath effects, suboptimal satellite geometry, long baseline lengths, or height discrepancies between reference and rover stations. Conducting data collection in multipath-free desert environments and employing final precise ephemerides allows for a clearer assessment of the inherent benefits of GPS+GLONASS integration, independent of multipath effects, unfavorable satellite geometry, or reduced-quality orbit products. This research will be extended in future work to investigate multipath effects in both static and kinematic PPP solutions, the performance of integrated PPP with MEMS-based inertial navigation systems and vision-based navigation, and the application of static and kinematic PPP in UAV-based photogrammetry and personal mobile mapping system for accurate estimation of the exterior orientation parameters of cameras and fixing ground control points. Such investigations are essential for improving automated image matching performance and reducing processing time relative to conventional workflows. Additional details on related research activities conducted at the University of Benghazi, aimed at enhancing image-based navigation, robotic navigation, and UAV products, are provided in [18-23].

2. Objectives and Methodology

The data used in this investigation were obtained from several projects conducted across Libya through the Engineering Consultancy Office at the University of Benghazi. Ten independent datasets were collected using a dual-frequency GNSS receiver operating in static mode under clear, unobstructed open-sky desert conditions. Each observation campaign lasted continuously for 24 hours. All datasets were processed under two processing configurations: GPS-only and GPS+GLONASS for the CSRS-PPP and PPP-WIZARD services, and GPS-alone for the APPS service. For each dataset, fixing durations began at 1 hour and have been incrementally increased up to a maximum of 24 hours. The 24-hour static PPP solutions obtained from the three services have been compared with the reference coordinates of the corresponding points, as provided by the Libyan Survey Authority and approved by the oil fields in which these points are located. Agreement between the PPP-derived static coordinates and the reference coordinates indicates that the corresponding service is free from systematic errors. Otherwise, the estimated systematic bias is quantified and taken into account when evaluating the time-dependent static PPP solutions. The resulting static PPP coordinate solutions have been assessed against the reference coordinates to compute absolute positioning errors in the Easting (E), Northing (N), and Height (H) components, as well as the two-dimensional (2D: E+N) and three-dimensional (3D: E+N+H) positioning errors. The results obtained from the ten stations have been subsequently subjected to statistical analysis to identify and remove outliers and to derive the final positioning accuracy indicators. The use of datasets collected from spatially distributed locations across Libya enabled an assessment of the effects of satellite visibility and geographic distribution on PPP accuracy and solution stability. Figure (1) illustrates the spatial distribution of the testing points across Libya.

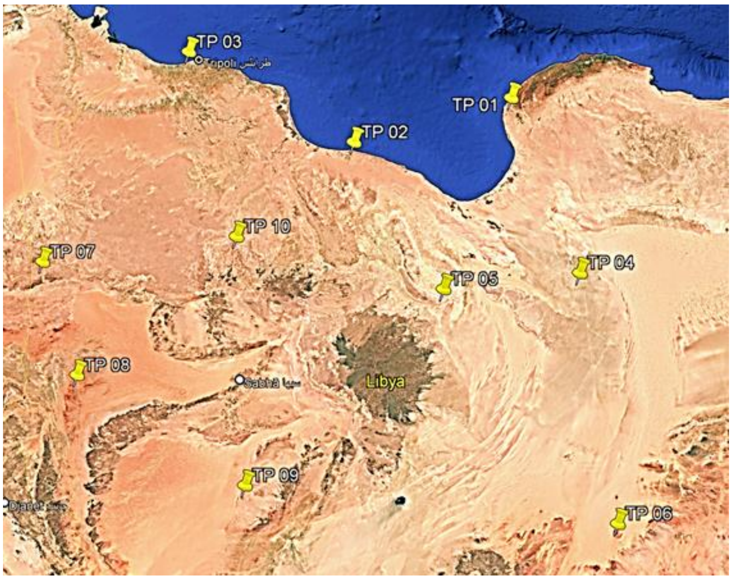

Figure 1 Testing points distribution across Libya

3. Results and Discussion

The average quality of E, N, H, 2D and 3D absolute differences in GPS-alone and GPS + GLONASS are shown in the following figures. Figures (1), (2), (3), and (4) are related to the quality of CSRS-PPP in N, H, 2D & 3D, respectively. Figures (5), (6), (7), (8), & (9) are related to the quality of PPP-WIZARD in E, N, H, 2D & 3D, respectively. Figures (10), (11), (12), (13), & (14) are related to the quality of APPS in E, N, H, 2D & 3D, respectively.

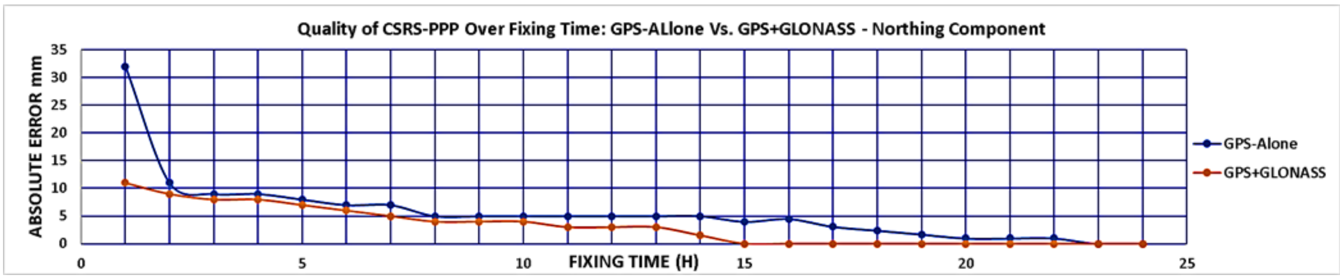

Figure 1 CSRS-PPP: Northing Quality: GPS-alone Vs. GPS+GLONASS

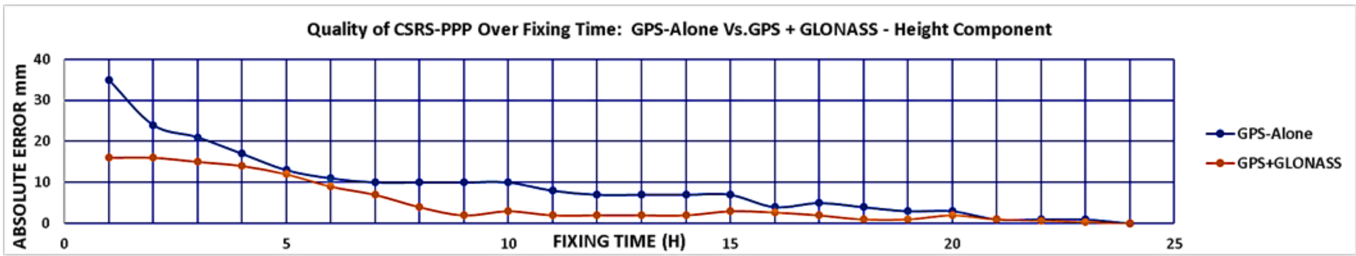

Figure 2 CSRS-PPP: Height Quality: GPS-alone Vs. GPS+GLONASS

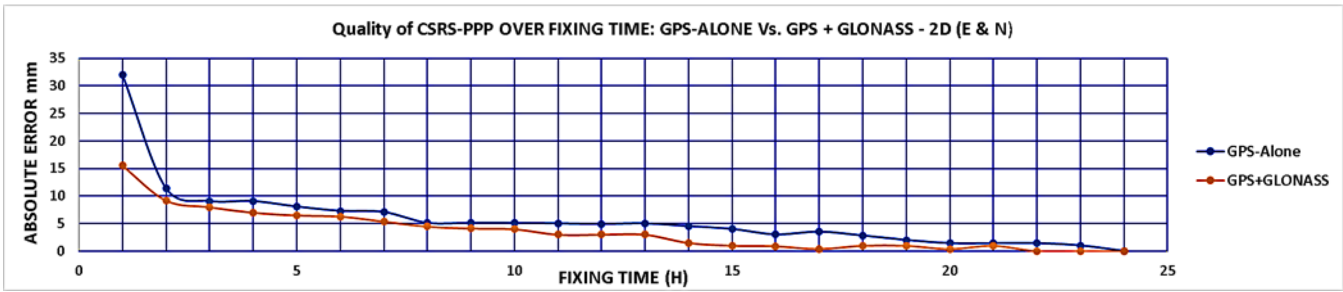

Figure 3 CSRS-PPP: 2D (E and N) Quality: GPS-alone Vs. GPS+GLONASS

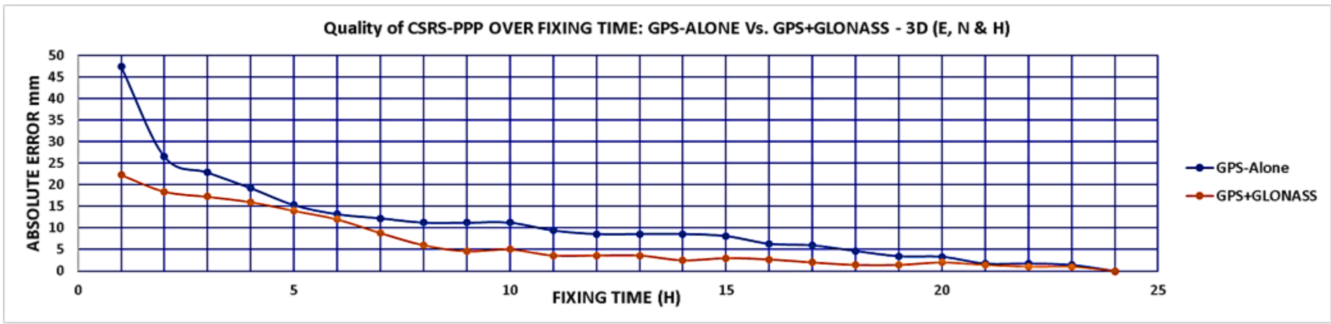

Figure 4 CSRS-PPP: 3D (E, N and H) Quality: GPS-alone Vs. GPS+GLONASS

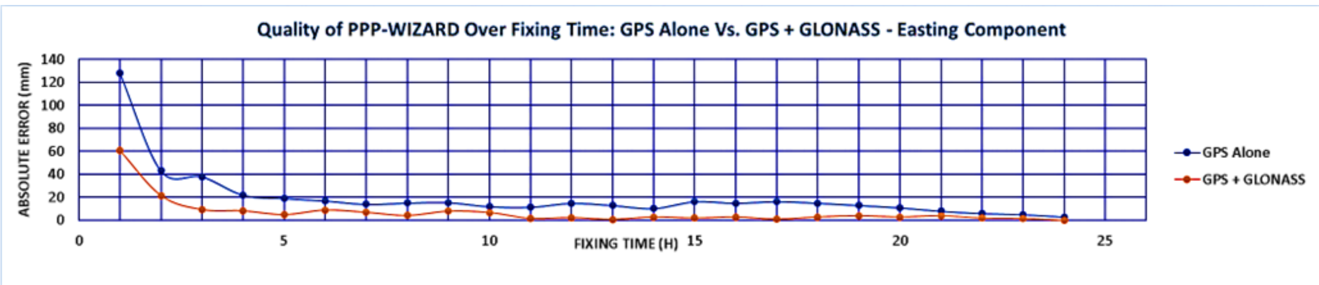

Figure 5 PPP-WIZARD: Easting Quality: GPS-alone Vs. GPS+GLONASS

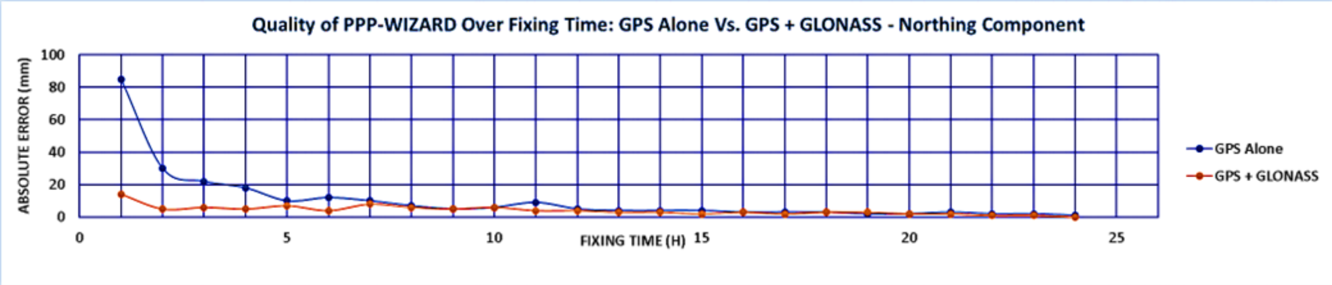

Figure 6 PPP-WIZARD: Northing Quality: GPS-alone Vs. GPS+GLONASS

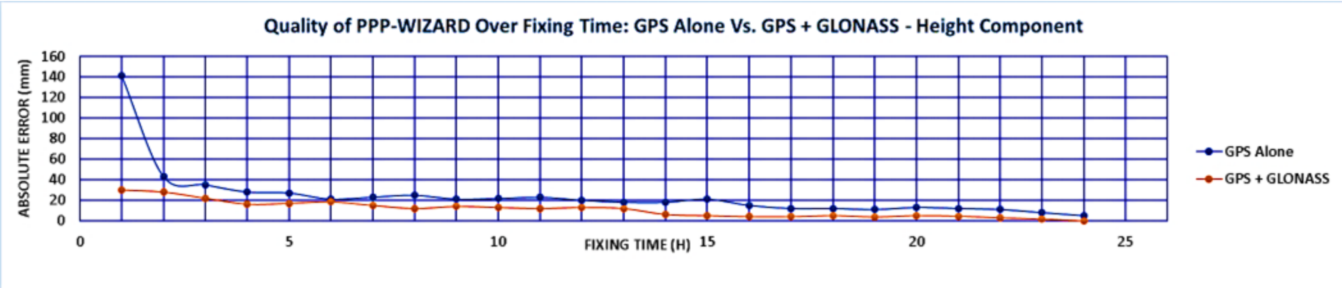

Figure 7 PPP-WIZARD: Height Quality: GPS-alone Vs. GPS+GLONAS

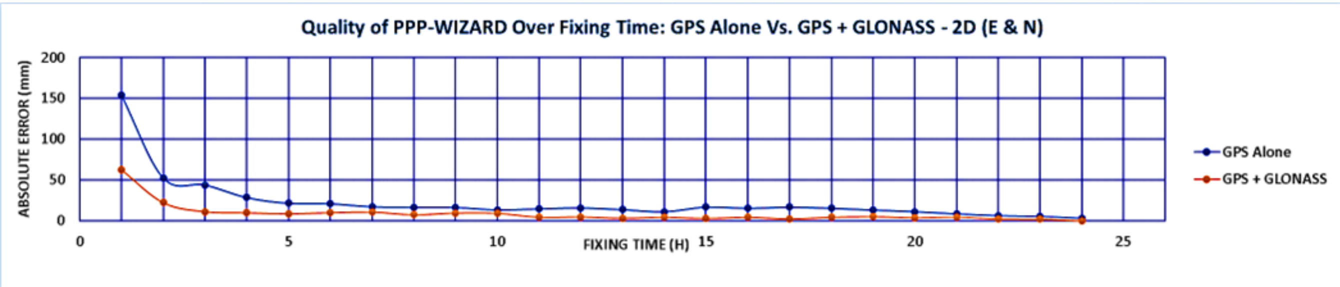

Figure 8 PPP-WIZARD: 2D (E and N) Quality: GPS-alone Vs. GPS+GLONASS

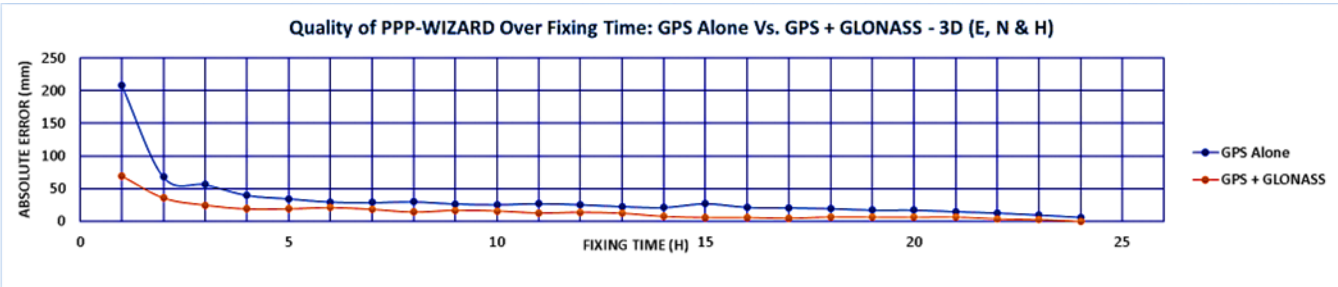

Figure 9 PPP-WIZARD: 3D (E, N and H) Quality: GPS-alone Vs. GPS+GLONASS

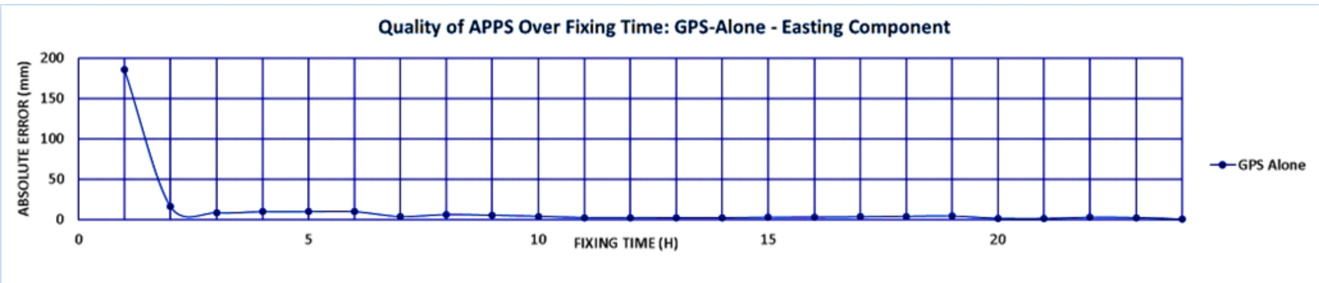

Figure 10 APPS: Easting Quality: GPS-alone Vs. GPS+GLONASS

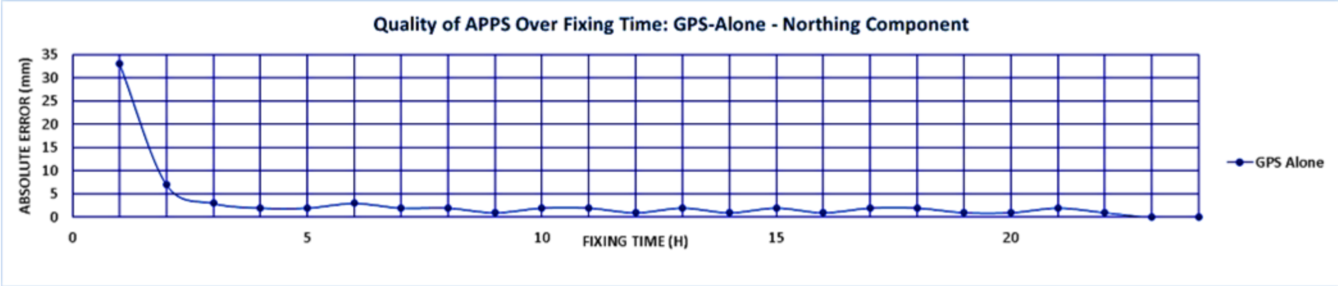

Figure 11 APPS: Northing Quality: GPS-alone Vs. GPS+GLONASS

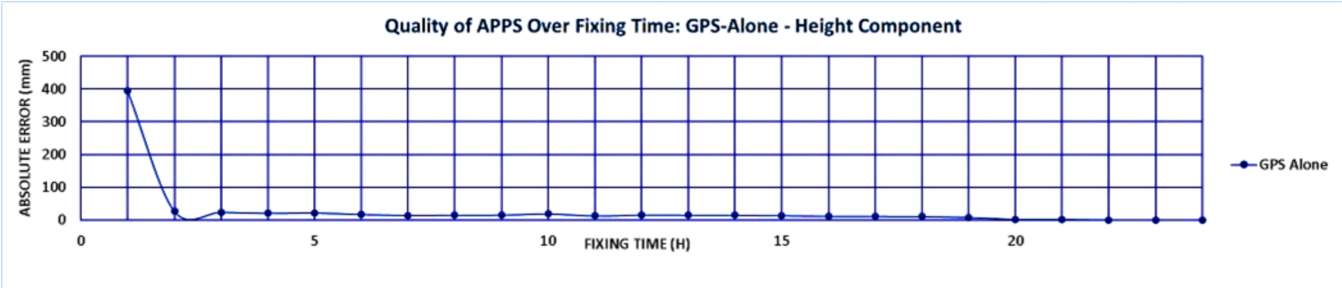

Figure 12 APPS: Height Quality: GPS-alone Vs. GPS+GLONASS

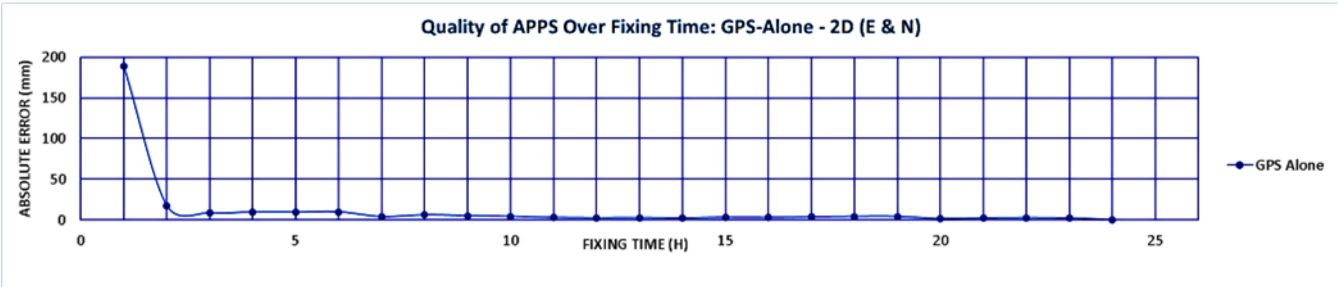

Figure 13 APPS: 2D (E & N) Quality: GPS-alone Vs. GPS+GLONASS

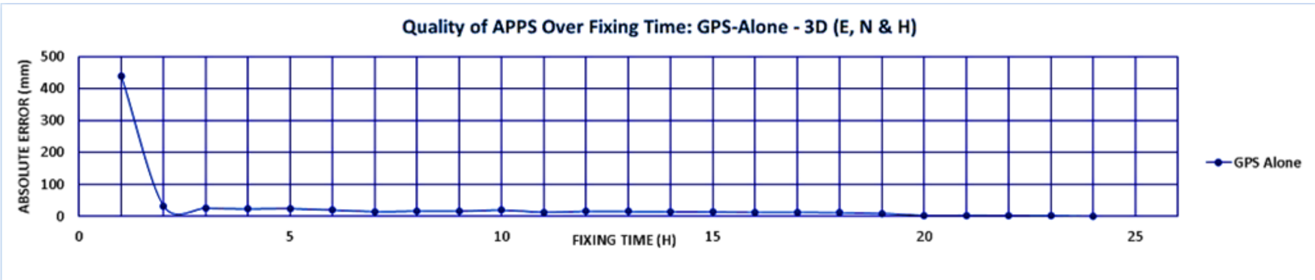

Figure 14 APPS: 3D (E, N & H) Quality: GPS-alone Vs. GPS+GLONASS

The results obtained from the CSRS-PPP and PPP-WIZARD services demonstrate that integrating GLONASS observations with GPS significantly improves solution reliability and overall positioning stability across all fixing intervals. The inclusion of the GLONASS constellation enhances satellite geometry, increases observational redundancy, and reduces the impact of periods with limited GPS satellite visibility. These advantages are most pronounced during short observation durations, particularly within the first fixing hour, when PPP solutions are highly sensitive to satellite geometry and convergence behavior. Also, the results show that although the improvement in mean absolute accuracy becomes marginal for longer observation periods, the multi-constellation configuration substantially reduces the occurrence of outliers and decreases the dispersion of coordinate residuals in all components. Moreover, the results illustrate clearly that even under optimal open-sky conditions, where multipath effects are minimal, the integration of GLONASS contributes measurably to enhancing the robustness of static PPP solutions. These improvements are attributed to the increased number of tracked satellites and the resulting improvement in satellite geometry, which leads to better dilution of precision (DOP). Improved satellite geometry also strengthens ionospheric and tropospheric delay estimation, while the increased number of observations raises the degree of freedom in the solution, allowing the exclusion of high-residual measurements and low-elevation satellites without degrading solution quality. Consequently, the 3D positioning accuracy achieved with one hour of static dual-frequency GPS + GLONASS PPP can only be reached after approximately 3-4 hours when using GPS-only observations.

Starting with CSRS-PPP, during this initial hour, absolute errors in the (N, H, 2D & 3D) components decrease markedly from (3.3, 3.5, 3.3 & 4.47 cm) for the GPS-only solution to (1.1, 1.5, 1.5 & 2.25 cm) for the GPS + GLONASS solution, respectively. After that the 3D quality increases slightly, reaching sub-centimeter accuracy after approximately 6 hours and 10 hours for the multi-constellation and GPS-only configurations, respectively. The Easting component exhibits negligible errors for both configurations, effectively rounded to zero, which is consistent with the near-symmetrical East–West satellite distribution. In contrast, such symmetry does not exist in the North–South direction due to satellite orbit inclination, resulting in larger errors in the Northing component. The higher inclination angle of GLONASS satellites reduces the region of limited northern satellite coverage, leading to improved Northing accuracy when both constellations are used. Figure (5) illustrates the 24-hour satellite sky distribution for GPS-only and GPS + GLONASS configurations.

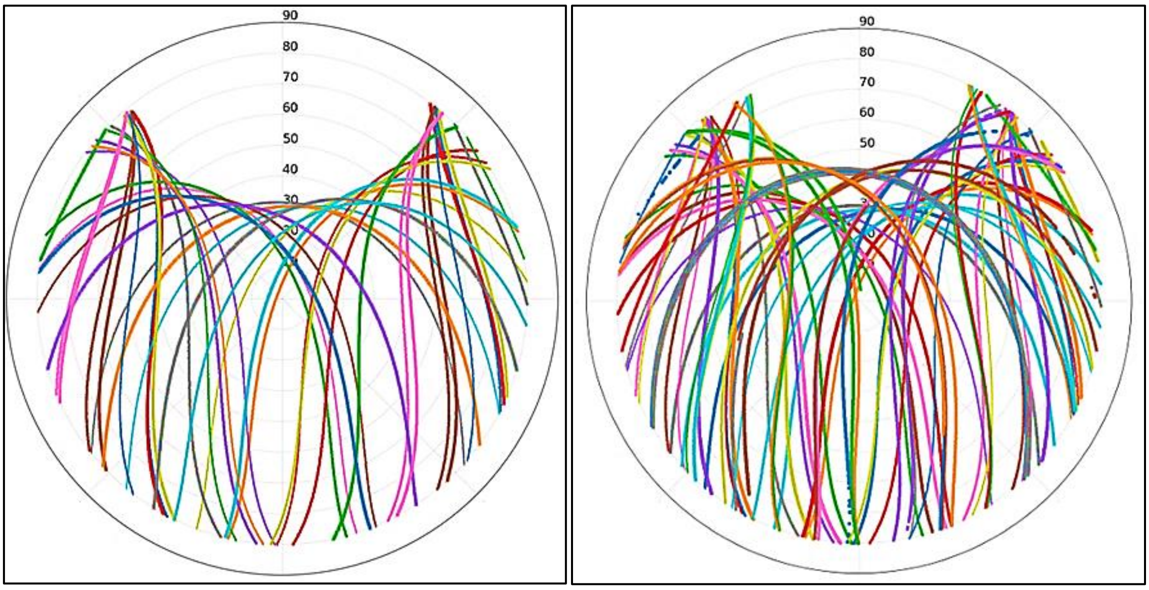

Figure 15 Satellite Sky Distribution: GPS-alone (left) Vs. GPS+GLONASS (right)

As for the PPP-WIZARD service, during the first initial hour, the absolute positioning errors in the (E, N, H, 2D & 3D) components are significantly reduced from (13, 8.5, 14, 15, and 21 cm) for the GPS-alone solution to (6, 1.8, 3, 6, and 7 cm) for the combined GPS + GLONASS solution, respectively. After that, the 3D quality of multi constellation solution increases slightly comparing to GPS-alone solution, rounded respectively about 2.5 cm and 6 cm after 3 hours before settling on 2 cm and 3 cm for the rest of observation time. Moving to the APPS service, the results show that GPS-alone static PPP using APPS has provided average absolute errors of (18, 3.5, 40, 19 & 43 cm) & (2, 1, 2, 2 & 3 cm) after 1 & 2 fixing hours in (E, N, H, 2D & 3D), respectively. After that the 3D quality has fluctuated to be within 3 cm +/- 1 cm for long period before reaching the level of less than 1 cm after nearly 20 hours of observations. By comparing the errors in E & N components in PPP-WIZARD and APPS solutions, it can be noted that errors in N components are bigger than that in E components which is unusual due to the reasons mentioned above. Such uncommon results can be attributed mainly to the quality of the estimation models of troposphere and ionosphere delays and the distribution of PPP monitoring stations across the fixing point, where the quality increases in well-distribution areas and reduced in areas away from the good estimation "coverage". The results further indicate that the positioning quality obtained from the PPP-WIZARD and APPS services in static mode is substantially better than that achieved in kinematic mode, which has been investigated in [11,14].

Overall, the findings confirm that multi-constellation GNSS integration is a critical factor in enhancing static PPP performance, particularly for applications requiring high accuracy over short observation periods. Among the investigated services, CSRS-PPP is identified as the most reliable, faster convergency time, and efficient solution, while PPP-WIZARD and APPS remain viable alternatives for longer observation durations. The results prove that the static solutions provided by these three free online services, using dual-frequency observations in open sky with final precise ephemeras with a few hours observation time, are considered to be stable, reliable, precise, and have the quality level to be used with the majority of engineering applications

4. Conclusion

This study has comprehensively evaluated the time-dependent performance of dual-frequency static PPP using three widely adopted free online services, namely: CSRS-PPP, PPP-WIZARD, and APPS, under optimal open-sky desert conditions. The analysis, based on 24-hour GNSS observations collected at ten well-distributed stations across Libya and referenced to coordinates officially approved by the Libyan Survey Authority, provides clear insight into the convergence behavior, accuracy evaluation, and relative robustness of single and multi-constellation PPP solutions. The results conclusively demonstrate that the integration of GLONASS observations with GPS significantly enhances PPP solution reliability and stability, particularly during the early convergence phase. Even in environments characterized by negligible multipath effects and sufficient satellite availability, the GPS+GLONASS configuration consistently outperforms the GPS-alone approach in terms of convergence speed, robustness, and resistance to outliers. This improvement is most pronounced within the first hour of observation, during which absolute errors in E, N, H, 2D & 3D components are reduced by (0.2, 2.2, 3, 1.8 & 2.22 cm) for CSRS-PPP and by (6, 6.5, 11, 9 & 13 cm) for PPP-WIZARD, respectively. Although the marginal gain in mean absolute accuracy diminishes with longer observation durations, the multi-constellation solutions continue to exhibit lower dispersion of residuals across all coordinate components. Notably, the 3D positioning quality achieved with one hour of GPS+GLONASS static PPP can only be attained after approximately 3–4 hours when using GPS-only observations.

A comparative assessment of the three online PPP services indicates that CSRS-PPP delivers superior overall performance, exhibiting both the fastest convergence and the highest positioning accuracy. After only one hour of observation, CSRS-PPP achieves 3D absolute errors of approximately 2 cm for GPS+GLONASS and 5 cm for GPS-alone processing. With increasing observation time, both solutions progressively improve, reaching sub-centimeter accuracy after approximately 6 hours and 10 hours for the multi-constellation and GPS-only configurations, respectively. PPP-WIZARD ranks lower in performance, providing a 3D accuracy of about 7 cm for GPS+GLONASS and approximately 20 cm for GPS-alone after one hour; however, neither configuration attains the 1 cm accuracy threshold even after 24 hours of continuous observation. The APPS service, evaluated exclusively under the GPS-only configuration, exhibits the weakest performance during the initial fixing interval, with a 3D error of approximately 45 cm after the first hour. Nevertheless, its convergence behavior improves rapidly with time, surpassing the PPP-WIZARD GPS-alone solution and closely approaching the performance of the PPP-WIZARD GPS+GLONASS solution during extended observation periods before reaching the level of 1cm after nearly 20 hours of observation.

Overall, the findings confirm that multi-constellation GNSS integration is a critical factor in enhancing static PPP performance, particularly for applications requiring high accuracy over short observation periods. Among the investigated services, CSRS-PPP is identified as the most reliable and efficient solution, while PPP-WIZARD and APPS remain viable alternatives for longer observation durations. Moreover, the results prove that the static solutions provided by these three free online services, using dual-frequency observations in open sky with final precise ephemeras with a few hours observation time, are considered to be stable, reliable, precise, and have the quality level to be used with the majority of engineering applications These conclusions provide valuable guidance for practitioners and researchers in selecting appropriate PPP services and observation strategies for high-precision geodetic applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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