**6th Intercontinental Geoinformation Days**

igd.mersin.edu.tr

# Continuous decimeters level real-time Precise Point Positioning in polar high latitude region

**Reha Metin Alkan [1], Mahmut Oğuz Selbesoğlu [1], Hasan Hakan Yavaşoğlu [1], Bilal Mutlu [1]**

[1] *Istanbul Technical University, Faculty of Civil Engineering, Department of Geomatics Engineering, Istanbul, Türkiye*

**Keywords**
Polar region
Marine survey
Real-time Kinematic GNSS
PPP

**Abstract**

In this article, the usability and accuracy assessment of the real-time Precise Point Positioning (PPP) technique for dynamic positioning in application areas with difficult atmospheric and topographic conditions, such as polar regions, has been investigated. Within this frame, kinematic Global Navigation Satellite System (GNSS) data collected during the ship voyage in the Southern Ocean region for the 6th Turkish Antarctic Expedition in 2022 was used. The GNSS data were collected over approximately 9 hours with a 1 Hz sampling rate by tracking all available satellite constellations. The data were processed using Net_Diff GNSS in-house processing software with a PPP solution with an ambiguity resolution (PPP-AR solution) approach using real-time products in the real-time Precise Point Positioning (RT-PPP) mode. The State Space Representation (SSR) products were retrieved from Centre National D'Etudes Spatiales / Centre for Space Studies (CNES) Analysis Center. The results showed that the real-time GNSS PPP solution provided a cm to dm level of accuracy. The overall results obtained from the study showed that the RT-PPP technique is an alternative to the relative method in challenging high-latitude regions. The results of the study will also contribute to many researchers who will work in the polar regions and make a meaningful contribution to the limited literature.

## 1. Introduction

Different types of human activities in the polar regions, including the Arctic and Antarctic regions, are increasing day by day. As a result, the positioning performance of GNSS in these regions attracts more attention, and its use with different approaches is becoming widespread. The real-time centimetre-level position information has critical importance in many scientific and practical applications carried out in these regions, including precise navigation, hydrographic surveying, rig positioning, offshore platform survey, geotechnical surveying, geohazard assessment, marine construction, pipeline, and cable layout, glacial erosion monitoring, environmental mapping, and assessment, seismology, and so on. To fulfill the positioning needs in these applications, the GNSS technique has been widely used. The method has gained immense popularity owing to its ease of application, provided by its high level of accuracy. GNSS can be used at any time of the day and in all weather conditions, even in temperatures as low as -40°C and below. This makes it a highly reliable and versatile method for positioning and navigation. Furthermore, almost the 24/7/365-day measurement capability of GNSS and its ability to operate with minimal personnel requirements make it a highly efficient and cost-effective tool. As a result, the GNSS has been widely adopted across various domains, including land, sea, and air applications, where accurate positioning and navigation are critical.

The possible highest level of accurate positioning can be provided with conventional relative techniques, both in post-process or real-time modes. Indeed, this method provides reliable, robust, and highly accurate positioning. However, in order to apply the relative method, an additional measurement must be made at reference station(s) with known coordinates, and an additional effort needs to transmit the corrections for real-time applications. In the case of post-processing, GNSS data processing software and an expert user are also required. The land-based reference station requirement is an important limitation in measurements made more than hundreds of kilometres away from shores, especially for remote marine areas like open seas and oceans. As known, the accuracy of the relative GNSS positioning is affected by the baseline length. Because in

* **Corresponding Author**

*(alkanr@itu.edu.tr) ORCID ID 0000-0002-1981-9783
(selbesoglu@itu.edu.tr) ORCID ID 0000-0002-1132-3978
(yavasoglu@itu.edu.tr) ORCID ID 0000-0002-3139-4327
(mutlubil@itu.edu.tr) ORCID ID 0000-0002-9763-0345

**Cite this study**

Alkan, R. M, Selbesoglu, O, Yavasoglu, H. H, & Mutlu, B. (2023). Continuous decimeters level real-time Precise Point Positioning in Polar high latitude region. Intercontinental Geoinformation Days (IGD), 6, 233-237, Baku, Azerbaijan

remote areas such as the polar region, where the lack of GNSS networks consisting of points with sufficient density, sparse or low-density reference stations, environmental constraints in the establishment of new ones, the number of logistics problems, extreme atmospheric and weather conditions are limited to the usability of the conventional relative technique in high latitude regions. It should be noted that distance-dependent errors induced by the atmospheric and orbital errors cannot be minimized by establishing long baselines in relative technique. In this method, as the distance between the rover and its reference receiver increases, the positioning accuracy decreases. Furthermore, more than thousands of km baseline-length are too much in order to fix ambiguities for obtaining cm-level accuracy. Depending on all these issues, the relative method may turn into an ineffective method with very low performance in this challenging geography.

The Precise Point Positioning (PPP) technique, which has almost become a standard GNSS positioning tool, stands out as an important alternative with its ease of application and accuracy close to that of the relative method. The fact that the method needs precise orbit and clock data together with GNSS data collected with only one receiver has made the PPP an effective positioning tool used in many different fields. The PPP is not affected by baseline-dependent errors like in relative technique due to not requiring reference station data. This provides the usability of this technique anywhere in the world freely. In remote areas such as the Arctic and Antarctic, it is much more economical to log raw GNSS observations and process them with the PPP technique for accurate 3D positioning rather than using a reference station or a control network.

However, despite all this, the most important shortcoming of the PPP technique is that it needs a long convergence time (typically 20-30 minutes or more) (Qu et al., 2023). This requirement has been a serious restriction for the use of the PPP technique in RT applications (An et al., 2023). However, with the advent of the 'IGS-RTS Project', real-time precise products started to be produced by many Analysis Centres (ACs) under the umbrella of IGS. This provides the emerging real-time PPP (RT-PPP) technique as a combination of PPP and Real-Time Kinematic (RTK) methods. The RT-PPP technique has been widely used in many static and kinematic applications with cm-dm level accuracy by using only one receiver's data without the need for any additional reference station (Abdallah et al. 2016; Wang et al. 2018; Monico et al. 2019; Di et al. 2020; Di et al. 2022; Savchyn et al. 2023; Yu et al. 2023). Although there are many studies on the performance of RT-PPP in mid and lower-latitude regions, there are very few studies on the real-time positioning performance of the technique in real marine remote area applications.

In this study, GNSS data collected during a ship voyage in the Southern Ocean (South Polar Region) were used. The data were processed in simulation mode (as if it were a real-time application) using real-time precise products (precise satellite clock and orbit corrections, biases, and other necessary data) provided by CNES, and real-time PPP coordinates were obtained. Finally, the performance analysis of the method was made by comparing the PPP-derived coordinates with the reference trajectory.

## 2. Field Kinematic Test

### 2.1. Data collection

To assess the accuracy performance of the RT-PPP technique, a kinematic GNSS data set collected with a 72.05 m long and 12.50-meter-wide research ship named Betanzos sailing in the Southern Ocean within the scope of the 6th Turkish Antarctic Expedition was used. The GNSS data collected on February 07, 2022, has an occupation time of approximately 9 hours in a 1-second measurement interval by observing from all available GNSS satellites. In the study, CHCNAV i90 Pro geodetic GNSS receiver was used, which was mounted on the ship deck. The i90 Pro receiver is capable of GPS, GLONASS, Galileo, and BeiDou satellites' observations with its 336 channels. The stated accuracy is given as 2.5 mm + 1 ppm RMS (pos.), 5 mm + 1 ppm RMS (height) with post-processing kinematics (PPK) under the open sky, without multipath, optimal GNSS geometry and atmospheric condition. In the time period when the measurements were collected, the ship sailed at an average speed of appr. 15 kph. The surveying area and kinematic test measurement are given in Figure 1 (Britannica, 2023 and Google Earth).

**Figure 1.** The Kinematic test measurement

### 2.2. Data processing

The real-time PPP coordinates of each measurement epoch (total 32,638 epochs) were calculated by processing the kinematic GNSS observations, Ephemeris Products (CNES/POD Products-CNT), and State Space Representation (SSR) precise products produced by IGS-RTS CNES Analysis Centre. The used CNES products include the real-time orbit, clock corrections, and the code and phase biases (CNES/POD Products-CNT). All calculations were carried out with Net_Diff v.1.14 software developed at the GNSS Analysis Centre of Shanghai Astronomical Observatory, Chinese Academy of Sciences. Net_Diff supports all signals of GPS, GLONASS, Galileo, and BeiDou satellite systems operating globally, as well as QZSS and IRNSS serving on a regional basis, for all single, dual, and triple frequency multi-GNSS observations (Zhang et al. 2020). The software can process the GNSS data in different ways, including RTK, PPP, PPP-AR, and PPP-RTK approaches. The software is open source on GitHub and can be downloaded at the address of http://202.127.29.4/shao_gnss_ac/Net_diff/Net_diff.html.

Although the GNSS data were collected from all satellite constellations through the measurements, only a combination of GPS (G), GLONASS (R), and BeiDou (C) observations were used. As data processing strategy for RT-PPP solution in Net_Diff v1.14 software, raw code and phase observations with undifferenced-uncombined version was processed based on kinematic RT-PPP with Ambiguity Resolution (AR) in simulation mode. According to the ambiguity fix percentage ratio results, it was found that only a few ambiguities were resolved with a ratio of 33%. Due to this low rate, the PPP-AR solution was considered to make a limited contribution to improving the results. It should be noted that the coordinates of a kinematic trajectory were estimated with forward and backward processing strategies. The priori troposphere was modelled based on Saastamoinen global model. Also, the ionosphere and wet troposphere were modelled by software, and Vienna Mapping Function (VMF1) model was used for troposphere mapping. In order to obtain the highest level of accuracy, phase wind-up, solid earth tide, and relativistic effects, corrections were applied, and Kalman Filter was used as an estimator. Besides, phase center offset values were obtained from igs14.atx file. Finally, the kinematic coordinates of the ship were obtained in the ITRF2014 reference frame.

The number of used satellites, PDOP values, and sky plot were plotted in Figure 2.

In order to demonstrate the performance of the method and to determine the provided accuracy, the reference trajectory was calculated within cm-level accuracy by resolving the carrier-phase ambiguities with the relative GNSS technique. For this purpose, a commercial software, CHCNAV Geomatics Office Software 2.0 (CGO 2.0), was used. The coordinates obtained from the RT-PPP solution were compared with the relative solutions (i.e., reference trajectory) for the horizontal position (2D) and height (Up) components for each measurement epoch and were plotted as a time series in Figure 3.

The differences in Figure 3 were summarized with accuracy measures, i.e., Standard Deviation (Std.Dev.) and Root Mean Square Error (RMSE). The calculated values were given in Table 1.

**Table 1.** Statistical results

| | Δn (cm) | Δe (cm) | Δ2D Pos. (cm) | ΔUp (cm) |
|---|---|---|---|---|
| max. | 110 | 96 | 140 | 60 |
| min. | -9 | -138 | 0 | -106 |
| mean | 4 | 5 | 16 | 16 |
| Std.Dev. | 7 | 17 | 11 | 14 |
| RMSE | 8 | 18 | 19 | 21 |

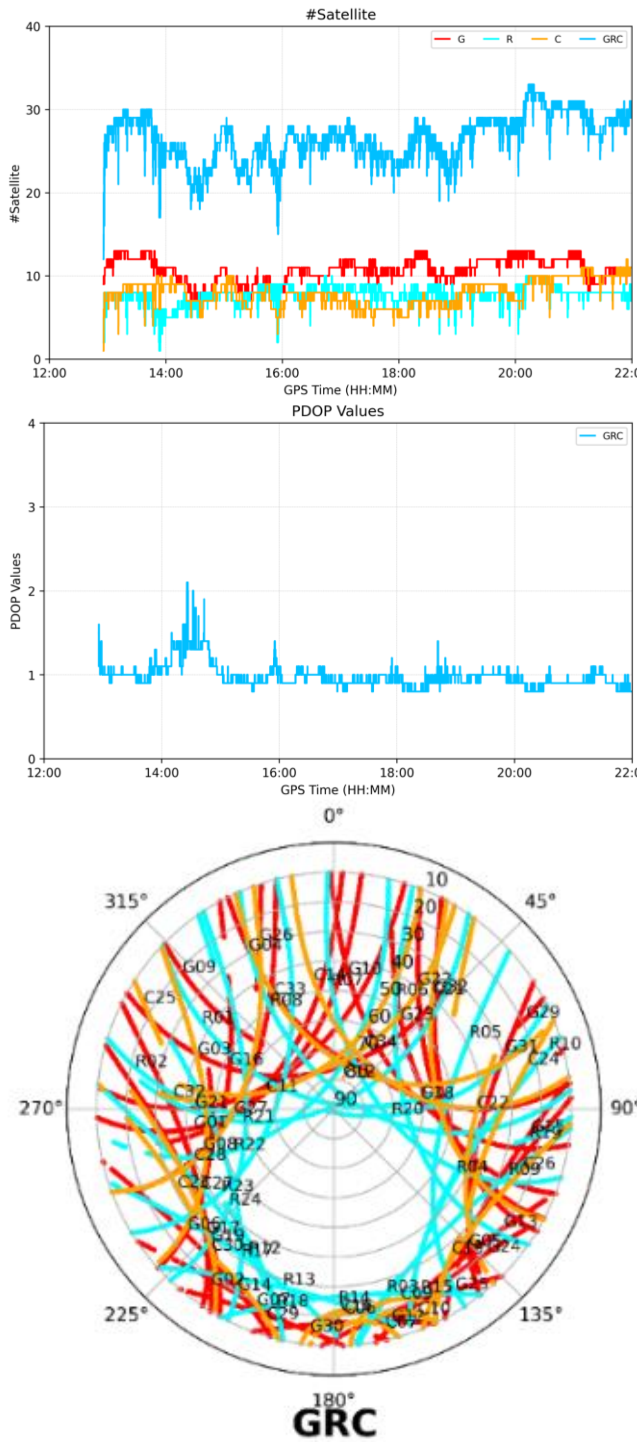


**Figure 2.** Satellite number (up), PDOP (middle), and sky plot (bottom)

## 3. Results and Discussions

In general, multi-constellation PPP significantly increased the number of satellites, and this improved the availability and reliability of positioning results (Zhao et al., 2022). This was also the case in our study. According to Figure 2, it was seen that the number of satellites for the multi-GNSS solution (GRC solution) increased significantly compared to the single-constellation systems. The mean number of observed satellites were found as 11, 8, 8, and 27 for G-alone, R-alone, C-alone, and GRC combination, respectively. In general, it was seen that the number of satellites and the PDOP value were inversely proportional; in other words, the PDOP value improved as the number of satellites increased. In the high latitude areas, the satellites were generally observed at lower elevation angles and over a shorter continuous period due to the GNSS orbit characteristics. Thus, the multi-GNSS observations increased the signal availability, and depending on this, positioning accuracy and reliability were improved.

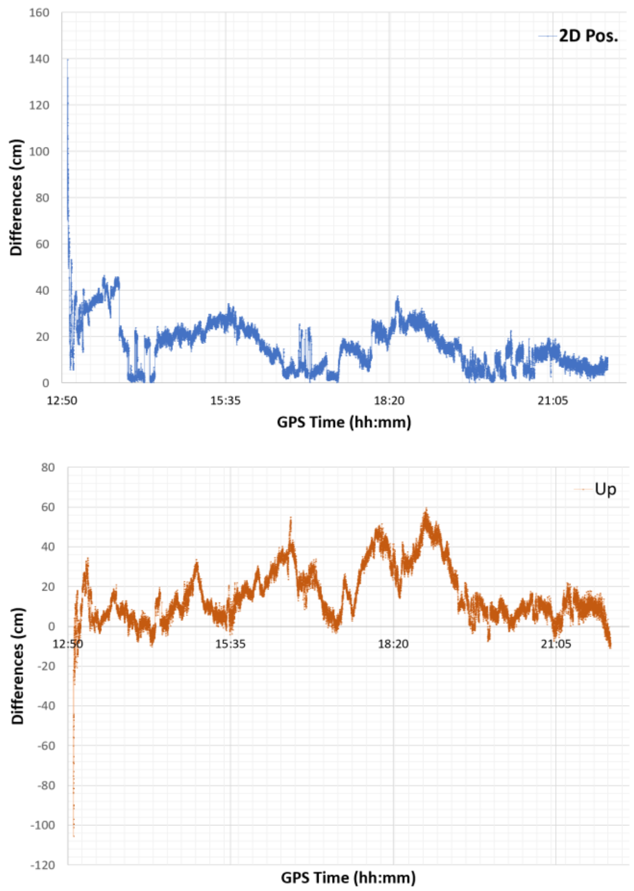


**Figure 3.** Comparison of the coordinates between RT-PPP and relative GNSS solutions

The results in Figure 3 showed that the multi-GNSS RT-PPP solution produced centimetre to decimetre level coordinate differences after the convergence period. The mean differences were found 16 cm for both 2D position and height components. Although this performance was generally well enough in such challenging conditions, the RT-PPP positioning accuracy in the high-latitude polar regions was found worse than that of medium and low-latitude regions. The most likely reasons for this were the configuration of the observed satellites, spatial geometric distribution of the observed GNSS satellite configuration, observing the satellites at low elevation angles, severe weather conditions, and atmospheric effects (mainly ionospheric effect).

Concerning accuracy, the RMSE of the RT-PPP solution were found as 19 cm in 2D horizontal and 21 cm in height components. As depicted in Table 1, the Standard Deviations (Std.Dev.) were found slightly better than the RMSE values as 11 cm and 14 cm for 2D horizontal and height components. The RMSE and Std.Dev. of the north-south components were found better than that of the east-west.

Due to the fact that PPP does not need base station data, the baseline length bias is not an issue like in the relative technique. Unlike the relative positioning method, the RT-PPP technique does not require additional GNSS data. So that, it has become a viable alternative to the conventional relative GNSS method.

## 4. Conclusion

The main goal of this paper was to evaluate the performance of the real-time PPP (RT-PPP) technique in high-latitude areas. For this purpose, a realistic kinematic test was carried out in the Southern Ocean, and 9 hours of kinematic GNSS data was collected. The dataset was processed with Net_Diff GNSS processing software in real-time mode. The overall results obtained from the study showed that the RT-PPP technique provides a centimetre to decimetre level of positioning accuracy in dynamic applications, especially for remote marine applications, without the need for additional GNSS reference data efficient and cost-effective way. These attainable accuracies satisfied the accuracy requirement of many real-time and kinematic remote marine and related applications, including the IHO, IMO accuracy standards, and others.

The overall results demonstrated that the RT-PPP technique can be successfully used for dynamic positioning under difficult atmospheric and topographical measurement conditions of polar high-latitude regions. It was clearly seen that the RT-PPP technique produces 3D position faster, allowing users to reduce the operational costs and time, and thus also the carbon footprint of each project.

## Acknowledgement

The authors gratefully acknowledge the IGS and CNES Analysis Centre for providing real-time products. Dr. Yize Zhang, the developer of Net_Diff software from the Shanghai Astronomical Observatory, China, is appreciated by the authors for providing the software. This study was carried out under the auspices of the Presidency of the Republic of Turkey, supported by the Ministry of Industry and Technology, and coordinated by TUBITAK MAM Polar Research Institute.

## References

Abdallah, A. M., Abd Rabbou, M., & El-shazly, A. (2016, April). Performance evaluation of real time precise point positioning (RT-PPP) in static & kinematic modes in Egypt. In Proceedings of the Arab Institute of Navigation (AIN) 2016 Melaha International Conference and Exhibition (pp. 25-27).

An, X., Ziebold, R., & Lass, C. (2023). From RTK to PPP-RTK: towards real-time kinematic precise point positioning to support autonomous driving of inland waterway vessels. GPS Solutions, 27(2), 86. https://doi.org/10.1007/s10291-023-01428-2

Britannica, (2023). The editors of encyclopaedia. "Southern Ocean", Encyclopaedia Britannica, https://www.britannica.com/place/Southern-Ocean. Accessed 31 May 2023.

Di, M., Zhang, A., Guo, B., Zhang, J., Liu, R. & Li, M. (2020). Evaluation of real-time PPP-based tide measurement using IGS real-time service. Sensors, 20(10), 2968. https://doi.org/10.3390/s20102968.

Di, M., Guo, B., Ren, J., Wu, X., Zhang, Z., Liu, Y., Liu, Q. & Zhang, A. (2022). GNSS real-time precise point positioning in Arctic Northeast Passage. Journal of Marine Science and Engineering, 10(10), 1345. https://doi.org/10.3390/jmse10101345

Monico, J.F.G., Marques, H.A., Tsuchiya, Í., Oyama, R.T., de Queiroz, W.R.S., de Souza, M.C. & Wentz, J.P. (2019). Real time PPP applied to airplane flight tests. Boletim de Ciências Geodésicas, 25(2). https://doi.org/10.1590/s1982-21702019000200009.

Qu, L., Du, Y., Wang, H., Jiang, W. & Wang, L. (2023). Multi-constellation and multi-frequency precise point positioning with fast ambiguity resolution on a global scale. Measurement, 211, 112642. https://doi.org/10.1016/j.measurement.2023.112642

Savchyn, I., Brusak, I. & Tretyak, K. (2023). Analysis of recent Antarctic plate kinematics based on GNSS data. Geodesy and Geodynamics 14(2), 99-110. https://doi.org/10.1016/j.geog.2022.08.004

Wang, Z., Li, Z., Wang, L., Wang, X. & Yuan, H. (2018). Assessment of multiple GNSS real-time SSR products from different analysis centers. ISPRS International Journal of Geo-Information, 7(3), 85. https://doi.org/10.3390/ijgi7030085

Yu, C., Zhang, Y., Chen, J., Chen, Q., Xu, K. & Wang, B. (2023). Performance assessment of multi-GNSS real-time products from various analysis centers. Remote Sensing, 15(1), 140. https://doi.org/10.3390/rs15010140

Zhang, Y., Chen, J., Gong, X. & Chen, Q. (2020). The update of BDS-2 TGD and its impact on positioning. Advances in Space Research, 65(11), 2645-2661. https://doi.org/10.1016/j.asr.2020.03.011

Zhao, J., An, J., Wang, Z., Ai, S., Zhu, L., & Zhang, B. (2022). Signal quality and positioning performance of GPS/BDS-3/GLONASS/Galileo in polar regions. Advances in Space Research, 69(6), 2541-2554. https://doi.org/10.1016/j.asr.2021.12.032