Effects of Ionospheric Delay on the Position Accuracy of GNSS Receiver: A Case Study at Burdwan University, India

Adewumi Adebayo Segun[1,2], Sukabya Dan[2], Rajkumar Mandal[2] and Anindya Bose[2]

[1]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, PMB 4000, Ogbomoso, Oyo State, Nigeria

[2]GNSS Laboratory, Department of Physics, The University of Burdwan, Burdwan, 713 104, India

Corresponding author: asadewumi@lautech.edu.ng

Abstract: The effects of ionospheric delay (ionodelay) on the positioning accuracy of GNSS receivers at the University of Burdwan, India are presented. One (1) Hz dual-frequency GPS constellation data were logged for 24 hours each day for a few days during the autumn season in October 2022 and the spring season in March 2023 using Leica GR 50 standard survey geodetic receiver and the logged files data were converted to Rinex observation data using RTKLIB converting software. GPS-GOPI software was used to obtain the Total Electron Content (TEC), the satellite bias (DCBsati), the receiver bias (DCBrx) and some other parameters that were used to estimate the ionodelay. The accuracy of position solution of the GNSS receiver on each observation day were determined through standard statistical estimate vis a vis Distance Root Mean Square (2DRMS), Circle Error Probable (CEP), Spherical Error Probable (SEP) and Mean Radial Spherical Error (MRSE) with use of GNSS positioning accuracy analysis tool (GLB GSOL software) and the results obtained were compared with each day ionodelay. The results of the analyses obtained reveal variations in TEC over observation days. The impacts of ionodelay on GPS PRN #6, PRN #7, PRN #10, and PRN #26 were determined on each day. Findings revealed that the TEC density along the satellites signal paths and visibility hours cause ionodelays of varying magnitude. It was observed that ionodelay was more prevalent on days characterized by solar and geomagnetic storms. The comparison of results reveals that the observation days in March 2023 were more susceptible to severe ionodelay than the observation days in October 2022, which might have been caused by the approach of the solar cycle towards its maximum equinox in March 2023. The accuracy of position solution of the receiver determined offline via 2DRMS, CEP, SEP, and RMSE shows more accurate values of position metrics in October 2022 than March 2023 at the same reference coordinate (RC) location using the same receiver. The 2D position solutions obtained show that the solutions for days with less ionodelay are more accurate than solutions for days with high ionodelay. Therefore, this study established the effects of ionospheric delay on the GNSS receivers' accuracy and its dependence on season.

Keywords: ionosphere, delay, GNSS, position, accuracy, performance

1. Introduction

The Earth's ionosphere or ionized upper atmosphere, is the solar-terrestrial environment, where electrons from solar radiation ignite atoms [1]. Ionospheric abnormalities result from uneven ion and electron distribution, leading to ionospheric delay (ionodelay), which causes rapid amplitude and phase changes in radio transmissions [2]. The ionosphere's dynamic changes compromised satellite navigation systems' ability to communicate, broadcast, and position accurately [3]. In addition to providing crucial data for ionosphere studies, ionospheric total electron content (TEC) is crucial for precise positioning and navigation in ionosphere studies. GNSS satellite-to-ground receiver electromagnetic waves experience group delay and phase advances due to the ionosphere's dispersive properties, and TEC can be determined by exploring these two delays [4]. Assessment of ionospheric TEC variations is now possible on global and regional scales using concurrent global observations, like GPS receiver extension networks, to monitor the ionosphere. The slant TEC (STEC) implies that the delay in GPS signals is proportional to the number of free electrons in a column with a one-square-metre cross-sectional area. Turbulence ionospheric delays cause small-scale errors of 2 m and large-scale errors of 10-30 m [5]. Therefore, this paper investigated the effects of ionospheric delay

I. Adimula et al. (eds.), *Proceedings of the 8th URSI-NG Annual Conference (URSI-NG 2024)*, Advances in Physics Research 12,
https://doi.org/10.2991/978-94-6463-644-4_16

on GNSS receivers' position accuracy and its dependence on seasons using a dual-frequency geodetic survey-grade Leica receiver.

2. Ionodelay Calculation from GNSS Observations Data

The ionospheric delay of the GNSS satellite signal is given by [6] and [7] as follows;

$$ionodelay = \frac{40.3}{f^2} \times VTEC \quad (1)$$

$$VTEC = STEC_{true} \times S(E) \quad (2)$$

$$STEC_{truei} = TECs + DCB_{sati} + DCB_{RX} \quad (3)$$

$$S(E) = \left\{ \left(\frac{R_e \times \cos E}{R_e + H} \right)^2 \right\}^{0.5} \quad (4)$$

S(E) is the mapping function, DCB_{sati} is the satellite bias, and DCB_{RX} is the receiver bias, Re is the earth's mean radius, E is the satellite elevation angle, and H is the ionospheric pierce (IPP) height. The STEC in a dual frequency GNSS receiver may as well be calculated by combining the relative code and carrier phase delay measurements of dual-frequency GNSS signals given by [7] as follows;

$$STEC_P = \frac{f_2^2 \times f_1^2}{(f_2^2 - f_1^2) \times 40.3 \times 10^{16}} \times (P_1 - P_2) \text{ in } TECU \quad (5)$$

$$STEC_\emptyset = \frac{f_2^2 \times f_1^2}{(f_1^2 - f_2^2) \times 40.3 \times 10^{16}} \times (\lambda_1 \emptyset_1 - \lambda_2 \emptyset_2) \text{ in } TECU \quad (6)$$

Where f_1 is the (L1, E1,G1, etc.) band carrier frequency and f_2 is the (L2, E2, G2, etc.) band carrier frequency of the GNSS considered in dual-frequency mode, P and $\emptyset$ are the pseudo range in metre and the carrier wave cycle, λ is the wavelength.

3. Experimental Setup

The experiment was setup to measure GNSS observation data using a Leica GR 50 survey-grade geodetic dual-frequency receiver at the GNSS Laboratory, Physics Department, the University of Burdwan, India for four days in both October 2022 and March 2023. A Leica AR 25 choke ring antenna was connected to the Leica GR 50 receiver, which was then connected to a computer desktop for data storage, as shown in Figure 1. Dual-frequency 1 Hz data logged for 24 hours each day were converted to Rinex 3.03 observation data using RTKLIB converter software [8]. The generated data was processed with GPS-GOPI software [9] to obtain GPS satellites (GPS PRN #6, PRN #7, PRN #10, and PRN #26) data that was used to estimate STEC, mapping function and deduced the ionodelay of the GPS satellites under consideration on each observation day. The Rinex 3.03 observation data was also post processed using GNSS Positioning accuracy analysis tool (GLB GSOL software) to estimate the accuracy of the position solution of the GNSS receiver on each observation day vis a vis peak to peak deviation, 2DRMS, CEP, SEP and MRSE. The position accuracy parameter was calculated by using user defined known fixed values of latitude, longitude and altitude. The accuracy of the position solution result of each day was compared with ionodelay on each observation day. These results were then used to deduce the effects of ionodelay on GNSS receiver's position accuracy. The goal of this study is to examine the effects of ionodelay on GNSS receiver's position accuracy in some days in spring and autumn at the same RC location.

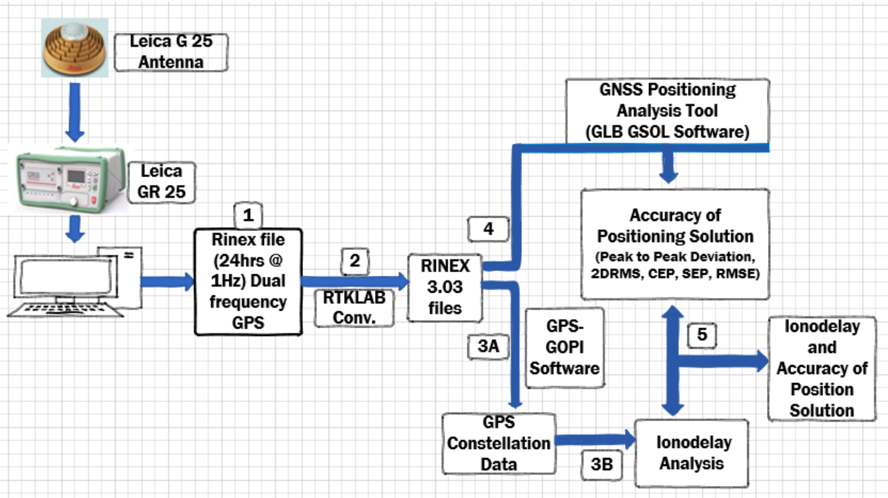
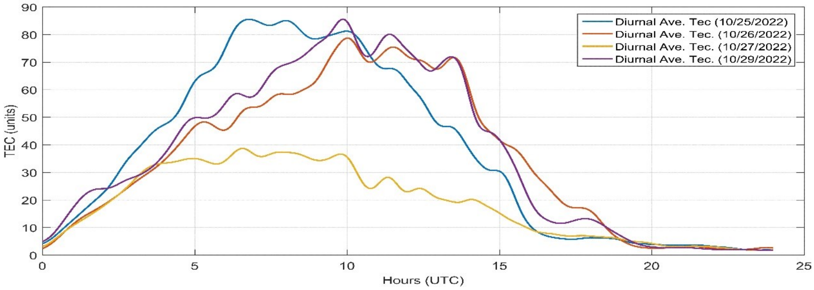


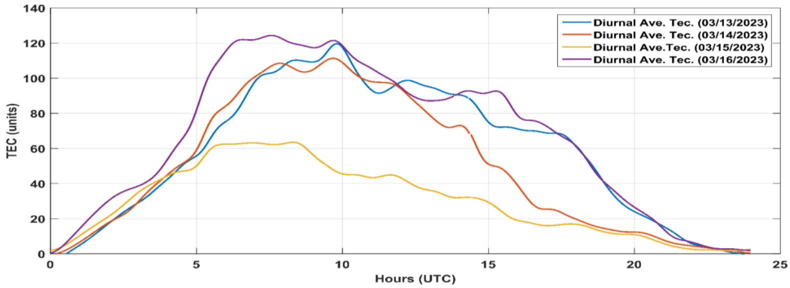
Fig. 1. Experimental Setup for GPS-based Ionospheric Delay study using Leica Geodetic Receiver.

4. Results and Discussion

Figures 2a and 2b show the TEC variations with time during the observation days in the two seasons. It was witnessed that the diurnal average TEC during the GPS visible hours on the observation days in October 2022 and March 2023 showed similar patterns. The pre-noon hours saw a steady rise in TEC, indicating the sun's rising hours. Higher values were observed during the noon hours, between 7:00 and 10:00 UTC, followed by a perpetual decrease. The maximum TEC value was due to solar radiation reaching its optimum. October 27, 2022, had the lowest TEC values due to a geomagnetically quiet and non-solar stormy day. Days 25 and 29 had the highest TEC values due to higher solar and geomagnetic storms (as observed from the dst index). In March 2023, days 15 and 16 witnessed the minimum and maximum TEC values, respectively. Days 13, 14, and 16 were characterized as solar stormy days, while day 15 was non-solar stormy. Figures 3a and 3b show the ionodelay patterns of four GPS satellites (PRN #10 and PRN #26) and GPS (PRN #6 and #7) on October 25, 26, 27, and 29, 2022, and March 13 to 16, 2023, respectively. The GPS satellites experienced maximum ionodelays during the noon hours due to maximum TEC. GPS PRN #26 was mostly visible during noon hours, resulting in its highest ionodelay. The least ionodelay was observed on October 27, due to low TEC density. GPS PRNs #6 and #7 experienced greater ionodelay in March 2023, with the minimum ionodelay on March 15. The highest delays occurred on March 16, 2023, due to higher solar storms causing severe satellite signal degradation. Generally, greater ionodelays were observed in March 2023 than in October 2022, which may be due to the solar cycle reaching maximum equinox during spring and the solar radiation or storm being at its peak in the spring season than in the autumn season.

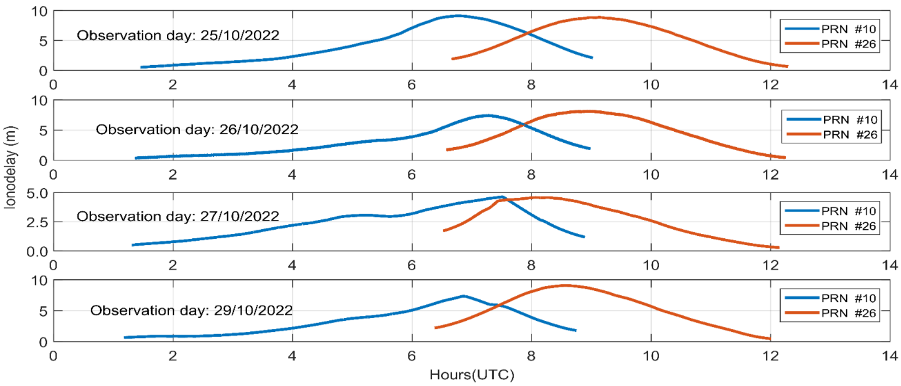


(a)

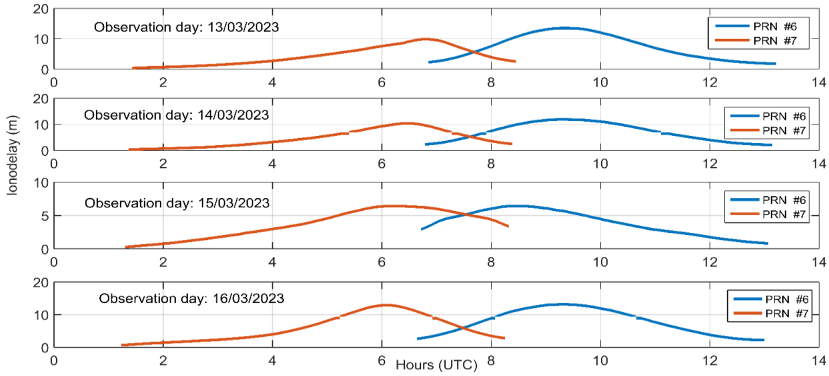


(b)

Fig. 2. Total electron content variations obtained via the Leica GR 50 satellite receiver during GPS satellites visible hours of some observed days in (a) October, 2022 and (b) March, 2023.



(a)



(b)

Fig. 3. Variations in ionodelay with respect to time of (a) GPS PRN #10 and GPS PRN # 26 on the observation days in October 2022 (b) GPS PRN #6, and PRN #7 on the observation days in March 2023.

Tables 1 and 2 show the results of the accuracy of the position solution obtained using the GNSS positioning accuracy analysis tool (GLB GSOL software) for the October 2022 and March 2023 observation days. The results showed that days with less ionodelay had better accuracy of position solution than those with higher ionodelay. The results showed that ionodelay had a significant effect on position accuracy, as noticed from the results of accuracy of position solution obtained from the two season under consideration. In overall, better accuracy of position solution was observed in October 2022 than March 2023 due to ionodelay. This finding reveals that ionospheric delay has a significant effect on the position accuracy of the GNSS receiver.

Table 1: Accuracy of position solution of the GPS satellites in relation to observation days in October 2022.

	Peak to Peak Deviation			Position accuracy metrics w.r.t RC position			
DATE	Lat. (m)	Long.(m)	Alt. (m)	2DRMS (m)	CEP (m)	SEP(m)	RMSE (m)
10/25/2022	7.917	11.269	27.343	6.154	2.439	4.103	5.041
10/26/2022	7.847	13.197	30.994	7.351	2.779	4.109	5.056
10/27/2022	6.184	12.025	30.836	6.783	2.525	4.052	5.083
10/29/2022	11.358	15.874	60.022	7.950	3.170	6.142	7.850

Table 2: Accuracy of position solution of the GPS satellites in relation to observation days in March 2023.

	Peak to Peak Deviation			Position accuracy metrics w.r.t RC position			
DATE	Lat. (m)	Long.(m)	Alt. (m)	2DRMS (m)	CEP (m)	SEP(m)	RMSE (m)
03/13/2023	12.625	19.670	32.266	7.599	3.158	6.268	7.944
03/14/2023	8.420	10.323	21.527	6.142	2.553	4.681	5.770
03/15/2023	9.071	13.122	28.784	6.860	2.845	5.587	7.065
03/16/2023	13.414	18.749	38.801	7.789	3.237	5.925	7.299

Figure 4a and 4b show the results of the analysis of the 2d position solutions of the observation days in October 2022 and March 2023. This analysis was done to validate the accuracy of the position solution and the effects of ionodelay on GNSS receiver's position accuracy. The 2D position solutions of the two figures show that the solutions for days with less ionodelay are more accurate in relation to the precise point positioning location than the solutions for days that have extensive ionodelay. It was also noticed from the 2d position solution scattered plots that the 2d solutions obtained from October 2022 was more accurate than that of March 2023 which is buttress the effect of ionodelay on the GNSS receiver's positioning accuracy.

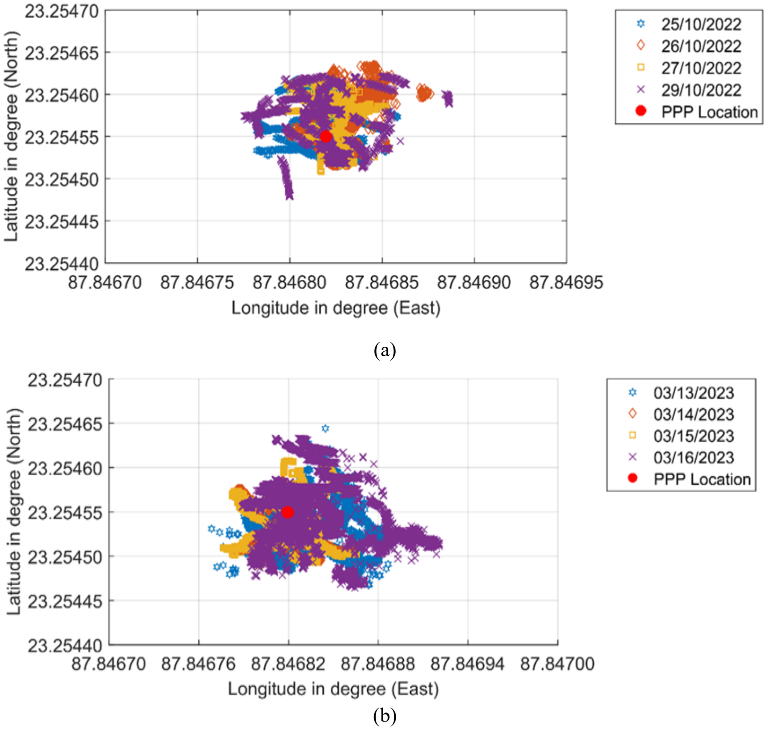


Fig. 4. 2d position solution scattered Plot of the processed observation data of the observation days in (a) October 2022 (b) March 2023

5. Conclusion

This paper investigates the impact of ionospheric delay on the accuracy of the position solution of the GNSS receivers. The study used 24-hour, 1-Hz, dual-frequency GPS satellite observation data from October 2022 and March 2023. The TEC values showed variations in TECs from day to day, with ionodelay affecting GPS PRN #6, PRN #7, PRN #10, and PRN #26 constellations. Ionodelay was more pronounced in the noon hours. The study also found out that the ionodelay experienced by satellites in March 2023 was greater than in October 2022. The 2D position solutions obtained showed that days with less ionodelay were more accurate in relation to precise point positioning (PPP) location. To improve positioning accuracy, the repeatability of GNSS positioning experiments on the same RC is necessary. The study establishes the effects of ionospheric delay on GNSS receivers' position accuracy and its reliance on TEC density and season.

Acknowledgment: The authors acknowledged the Nigeria Tertiary Education Trust Fund (TETFUND) for financial support through TETF/ES/UNIV/OYO STATE/TSAS/2020 grant and the GNSS Laboratory at Burdwan University, West Bengal, India, for technical support.

Declaration of Interest: The authors have no competing interests to declare that are relevant to the contents of this manuscript

References

[1] Kamide, Y., Chian, A. Handbook of the Solar-Terrestrial Environment, Ionosphere In: (eds.), pp.189-220, Springer, Berlin, Heidelberg. (2007) https://doi.org/10.1007/978-3-540-46315-3_8.

[2] Chen, Z, Liu, Y, Guo K, Wang J. Study of the Ionospheric Scintillation Radio Propagation Characteristics with Cosmic Observations. Remote Sensing, Vol. 14, pp. 578. (2022) https://doi.org/10.3390 /rs14030578.

[3] Otsuka, Y, Jin H, Shinagawa H., Hosokawa, K., Tsuda, T. Ionospheric Variability. In: Kusano, K. (eds) Solar-Terrestrial Environmental Prediction. Springer, Singapore (2023). https://doi.org/10.100 7/978-981-19-7765-77.

[4] Rui Zhang, Wei-wei Song, Yi-bin Yao Chuang Shi, Yi-dong Lou and Wen-ting Yi. Modeling regional ionospheric delay with ground-based BeiDou and GPS observations in China. GPS Solution, Vol.19, pp. 649–658, (2015). https://doi.org/10.1007/s10291-014-0419-z.

[5] Gennady A. Zhbankov, Nikolay P. Danilkin, and Olga A. Maltseva. Influence of the ionosphere on the accuracy of the satellite navigation system Acta Astronautica Science Direct Elsevier, vol. 190, pp. 194-201, (2022). .

[6] Desai MV and Shah SN. The GIVE ionospheric delay correction approach to improve positional accuracy of NavIC/IRNSS single frequency receiver. Current Science Vol.114. pp. 1665–1676, (2018). https://doi.org/10.18520/cs/v114/i08/1665-1676

[7] Dan, S, Santra, A., Mahato, S, Koley, C, Banerjee, P., & Bose, A. On use of low cost, compact GNSS receiver modules for ionosphere monitoring. Radio Science, Vol, 56, pp. 1-11. (2021). https://doi.org/10.1029/2021RS007344

[8] RTKLIB: An Open Source Program Package for GNSS Positioning. (2020). http://www.rtklib.com/

[9] GPS_TEC Ver. 3.02: A freeware program package for TEC derivation from GPS.(2020) https://seemala. blogspot.com/

.