EXAMINING THE EFFECT OF MAGNETIC FIELD ON THE ACCURACY OF GLOBAL NAVIGATION SATELLITE SYSTEM RECEIVERS

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Abstract: The upcoming technology to measure any given point is the Global Navigation Satellite System, also called GNSS. In many fields of science and technology, satellites are used to provide autonomous Geo-spatial positioning. It discovers their location (Latitude, Longitude, and Altitude) to high precision using time signals transmitted. This research is to find out the effect of the magnetic field and the accuracy of GNSS receivers. In this context, have a preliminary study on the magnetic field's outcome to the GNSS observation. The primary purposes are to analyze the magnetic field surveys on the positional accuracy of GNSS, the event of the magnetic field on GNSS signal, and examine the effect of a geomagnetic substorm on GNSS observation. This research contains the qualitative analysis conducted using the selected studies. The magnetic field effect on the GNSS antenna performance, observation, and GNSS signals as studied and stated by the authors of the reviewed previous research activities. All the analyses that the magnetic field changes contain a specific effect over the key GNSS observations. And for the specifications of point accuracy and millimeter level precision, this research gives us the impact of the magnetic field that cannot be neglected. This study recommended considering the external and the internal areas, magnetic and metal item effect when using GNSS notice for land surveying and construction surveying activities. And also recommended getting pre-knowledge about heavy substorm and other magnetic fields are effect weather before starting any GNSS observation to harvest the maximum output with limited errors through the successful project.

Index Terms: Geomagnetic Substorm, Magnetic Field, Position accuracy

1 INTRODUCTION

Presently satellites are used in many areas like science and technology in order to determine independent data using geo-spatial positioning. It accurately provides precise and accurate location information (Latitude, Longitude and Altitude) using time signals' transferring (electromagnetic wave). GNSS is a combination of the United States' Global Positioning System (GPS) and Russia's Global Navigation Satellite System (GLONASS). China's BeiDou navigation system (BDS) and European Union GLONASS were fully operational in 2021. Japan's Quasi-Zenith Satellite System (QZSS) and India's Indian Regional Navigation Satellite System (IRNSS) are real-time regional satellite navigation systems. The pseudo-range is one of the most important factors which determines the GNSS positioning. To measure this, range the time of flight of radio signals are used. The pseudo-range is considered here because the true capacity can be subjected to many errors due to many reasons when the signals are received.

There are specific reasons which cause the accuracy of the relevant positions. Those can be described as the accuracy of the satellite positions (Ephemeris), receiver timing bias or tracking errors, facility to the model atmosphere (Ionospheric and Tropospheric) bending, procedural errors in the field, coordinate transformation errors, Dilution of Precision (DOP), multipath errors. Signals from the GNSS satellites travel a long distance to reach the GNSS receiver. It can cause errors in the calculation in position; even a tiny deviation time results in significant position errors. The measuring effect of the magnetic field is instrumental in minimizing those errors.

Global Navigation Satellite System (GNSS) signals contain countless waves and navigation data to allow the users to calculate the traveling time from the Satellite to the receiver. GNSS provides small Electronic Receivers' ability to determine their position by measuring the distance to the Satellite. In magnetic fields area signal, transmitted time can delay by magnetic field effect. The impacts of magnetic fields are usually found in changeless magnets. Magnetic material, attraction, or repel other materials. Magnetic fields are produced by electrical appliances, power lines, electromagnets, and everything that carries electric current. Magnetic fields are formed at varying levels at different metallic structures. The surrounding area near the GNSS receiver antenna, such as magnetic or metallic structures forming magnetic fields, can interfere with the GNSS signals. It can result in errors in the position calculation. In construction sites, tunnels, and other sites, they have different electrical devices and have a magnetic effect. Then observation results can be an error. This study examines the impact of magnetic fields on the positional accuracy of GNSS receivers. It was essential to understand the magnetic field's effect in land surveying and construction surveying fields to complete their works more accurately and efficiently.

2 METHODOLOGY

This research is based on secondary qualitative data. The main objective of this research is to discuss the effect of magnetic fields on the GNSS observation. In this chapter, all the papers were selected relevant to the research domain. A comprehensive analysis of the methodologies was then conducted considering various research papers written with present-day related information. Solar and geomagnetic activities are complex at all times. GNSS is a signal passing the earth's planet ionosphere; an error budget occurs to the signal. The most degrading effect is also the occurrence of scintillation to polar latitudes (65°–90°) geomagnetic latitudes) and the equatorial bands (extending from20°N to 20°S geomagnetic latitudes). Large-scale plasma construction is improved during high geomagnetic storms. The plasma structuring mechanism is dominated by the interplanetary magnetic field (IMF) and magnetosphere. GNSS frequencies and amplitude do not influence auroral and polar latitudes. The phase scintillation index, Sigma Phi, and PLL phase tracking jitter are defined by scintillation incidence. PLL Phase Tracking Jitter is a calculated performance of the tracking receiver. Scintillation will significantly interfere with the tracking performance of the GNSS receiver. Rapid phase changes and exceeds the phase-locked loop during phase scintillation. Then loss the phase lock. PLL jitter variation increases. Evaluated by the tracking jitter variation, the receiver tracking efficiency, under heavy scintillation, greatly deteriorates. A quadratic fit will represent the receiver PLL jitter variance's dependency on phase scintillation (Aquino & Sreeja, 2013).Auroral disturbances arise from the precipitation of energetic electrons into the high latitude ionosphere along global magnetic field lines. Aurora occurs due to the interaction between the solar wind and the magnetic field of the Earth. This event can be identified as a magnetospheric sub storm, where anomalies in electron density are correlated. It is possible to degrade GPS receiver tracking performance in the presence of the effects of scintillation. The efficiency of receiver tracking performance mainly depends on the number of cycle slips observed and the number of missed measurements during re-acquisition times. Rapid combinations can be seen in phases. The GPS signal triggers a Doppler change, which could be greater than the phase lock loop bandwidth (PLL), which results in a loss phase lock. These results positively influence monitoring tracking loops that use codeless Semi-codeless technology and semi-codeless technologies. During the data collection time, anomalies in the density of auroral electrons were found during a moderate-major geomagnetic storm. The efficiency of degraded receiver tracking was mainly observed in conjunction with the storm duration. Scintillations lasted for several hours during this incident, significantly degrade the output monitoring of the receiver network. The efficiency of the semi codeless receiver is encouraged (Skone & Jong, 2000).

Geomagnetic storms are caused by solar disturbances impacting the magnetic field of the Earth. In combination with ionospheric storms, geomagnetic storms exist. A change in the magnetic field causes geomagnetic storms. During a geomagnetic storm, the earth’s magnetic field can change up to 30 000 nT on Earth. Modern navigational system’s radio-wave signals reflect or transmit across the ionosphere. The klobuchar model is exploited to correct ionospheric measurements of single-frequency GPS receiver errors. To restore the ionospheric impact measurements, the Klobuchar model, the official correction model transmitted by GPS satellites, forecasts the vertical TEC at a given time and location. GPS receiver signal lock failure can also occur if a high rate is open. Changes in TEC variability affect, in particular, during geomagnetic storm activity cycles. Large storms have profusely affected the communication and navigation systems in GPS due to an increase in electron density gradients. During the post-sunset to midnight hours effects are mostly confined. Satellite signals evince strong scattering at equatorial and polar latitudes. A frequency change in the obtained signal is triggered by intense phase scintillations, resulting in the receiver lock's failure. The receiver gets some time to re-initialize or re-acquire. A reduction in the number of GPS signals locked by a consumer receiver can result in low navigation accuracy. In the analysis, the input data is the TEC values calculated from the phase difference of the GPS receiver frequencies L1 and L2 (Raoet al., 2009).

The inhomogeneous ionosphere structure and magnetic field presence influence the position of the GPS. A 3-D Ray Tracing calculating Software for Radio Waves in the Ionosphere, known as the Jones 3-D Ray Tracing Program, can be used to determine the properties of GPS signals due to the magnetic field's effects. After all the subroutines are compiled and designed, the entire program is run. The inputs are the transmitter's position (longitude, latitude and height above ground range), the frequency of the GPS carrier, the propagation direction (elevation and azimuth), the height of the receiver and other related input values. The ionosphere has to be mathematically modelled before being performed using Jones 3D Ray Tracing software corrections for GPS positioning. Electromagnetic waves transmit their beams in the magnetic and electric fields; the two fields influence the direction. As solar interference disturbs the geomagnetic environment, the ionosphere is disrupted and the radio ray path is also disturbed. The effects of the magnetic field of the Earth contributes to a substantial direction of non-planar rays. The effects of the GPS signals were correlated with the horizontal ionospheric gradient and magnetic field. Using the Jones 3D Ray Tracing software and MATLAB, the results were obtained from the simulation (Nagarajoo & Fah, 2013).

3 ANALYSIS

The first methodology uses flashing data collected by NovAtel/AJ Systems GSV4004 receiver during the entire solar cycle period. A Septentrio PolaRxS receiver during the ascending phase of the current solar cycle is used. The variance of the error calculates receiver signal tracking performance at the PLL output and jitter variance. The IMF Bz curve has been changed to account for this delay for each occurrence and match the ground-based scintillation index observations. Figure 1 show study of the link between the Sigma Phi phase scintillation levels and the tracking output of the Bronnoysund-located PolaRxS receiver for various scintillation levels detected on different days in 2012.

 ISSN 2714-1837

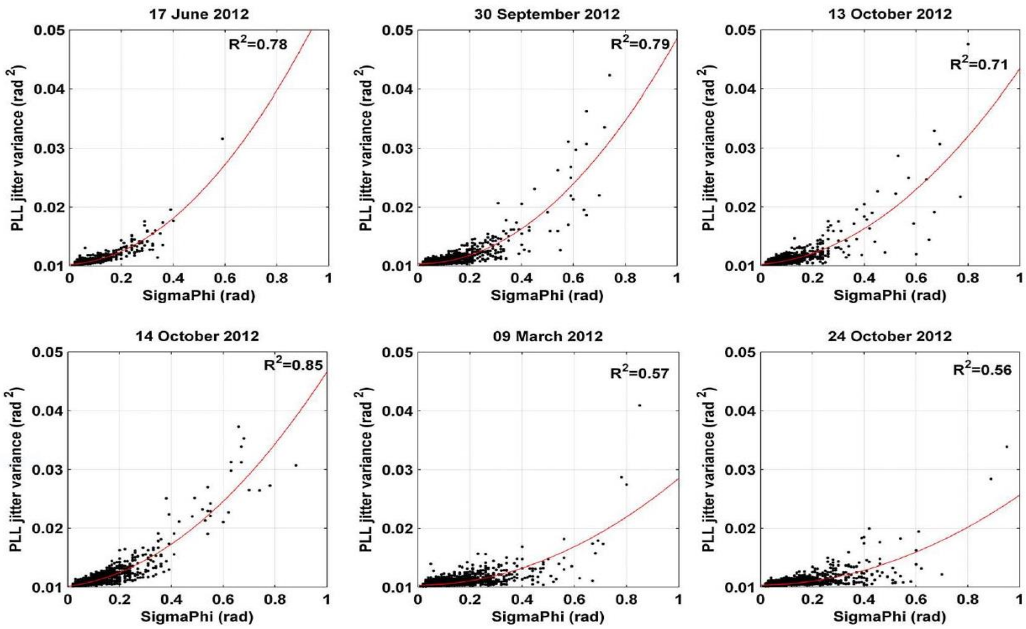


Figure 1. Variation of the receiver's PLL jitter variation as a function of Sigma Phi, the phase scintillation index, with scintillation levels increasing from left to right

Graphs show PLL jitter variance and scintillation levels are increase parallelly. There is a connection between PLL jitter variation and the amplitude scintillation index. Study of the link between IMF Bz's southward reversals and the frequency of stage scintillation, with an effect on monitoring GNSS receivers tracking Performance. The findings confirm that geomagnetic influence plays a dominant role in regulating the occurrence of scintillation at this station rather than solar activity. Tracking jitter variation evaluates the receiver tracking performance under heavy scintillation. A quadratic fit represented the requirement of the receiver PLL jitter variance on phase scintillation. GNSS signal influences the geomagnetic field on the high scintillation day (Aquino & Sreeja, 2013).

The second methodology measures receiver tracking performance efficiency mainly depending on the number of cycles slips observed and the number of missed measurements during re-acquisition times. Receiver efficiency relation cutting-edge auroral electron density was found during a large geomagnetic cycle during the test period. The following figure displays each receiver's tracking output in terms of the observed L2 period slips and incomplete L2 step measurements at each epoch for each satellite. The efficiency of receiver tracking performance mainly depends on the number of cycle slips observed and the number of missed measurements during re-acquisition times. Receiver efficiency relation cutting-edge auroral electron density was found during a large geomagnetic cycle during the test period. Figure 2 displays each receiver's tracking output in terms of the observed L2 period slips and incomplete L2 step measurements at each epoch for each satellite.

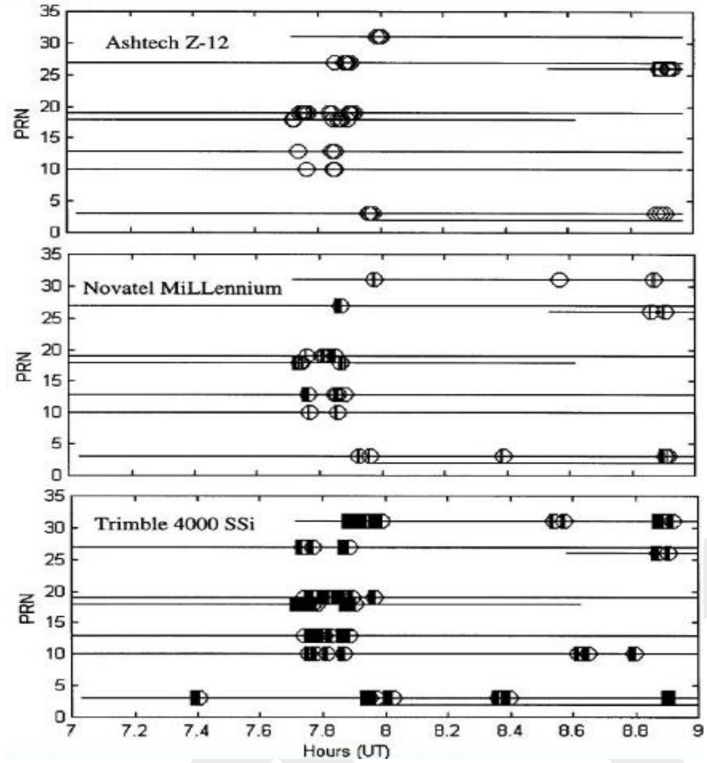


Figure 2. L2 phase tracking performance in individual satellite

The L1 monitoring performance was not changed significantly during this practical. During the 20 minutes and shorter discrete intervals, all receivers experience degraded tracking performance. Receiver efficiency variations are due to several variables, such as antenna gain patterns, loop bandwidth monitoring, and internal processing algorithms. It is impossible to infer the limiting factors for a given receiver. (Skoe & Jog, 2000).

In the third methodology show, the result of rapid phase variations, this loss of locks is triggered by exceeding the receiver's phase lock-loop (PLL) bandwidth in the received signal carrier. This results in a reduction in the number of GPS signals locked by a consumer receiver's bad accuracy in navigation. During a magnetically quiet day, step slips are often observed, such as those seen in the figure 3 and figure 4.

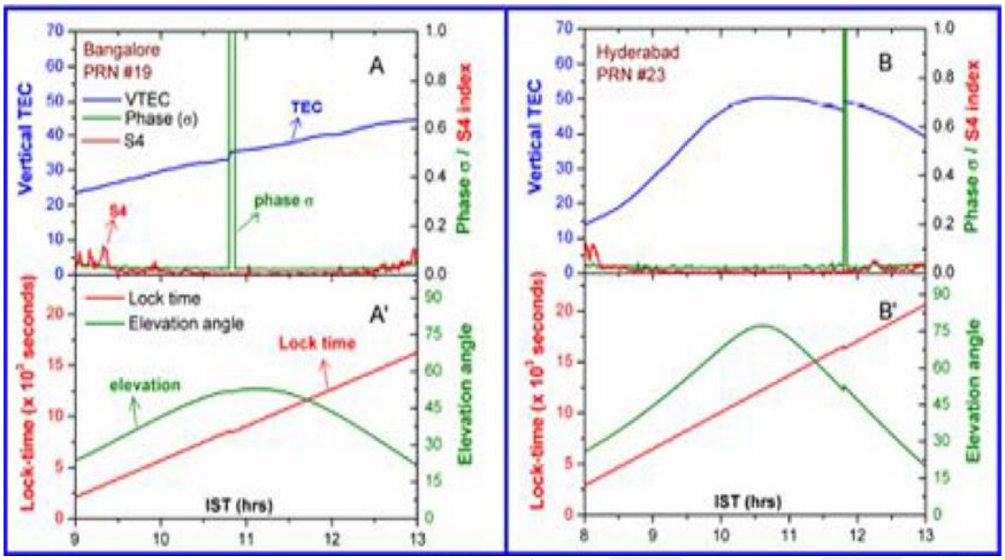


Figure 3. Phase slips observation in GPS receivers during a quiet day, 6 November 2004

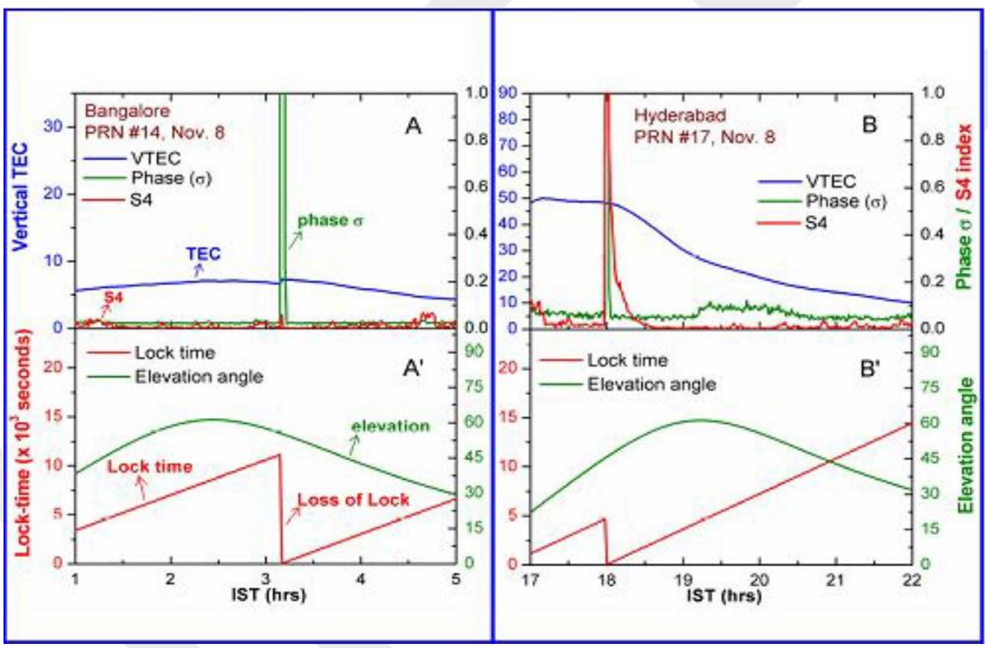
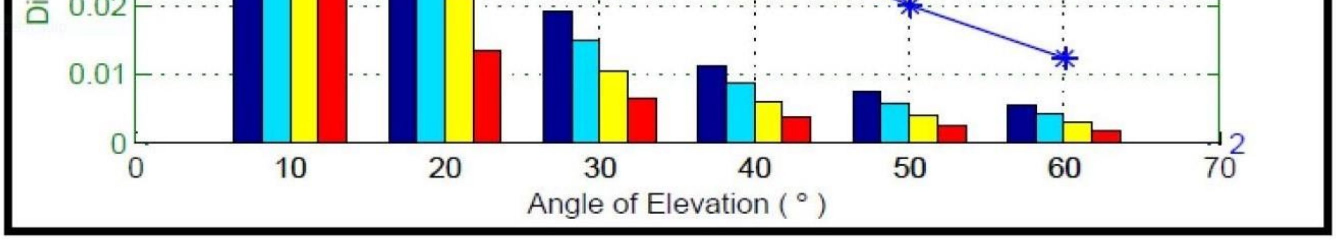


Figure 4. Phase slips observation in GPS receivers during a geomagnetic storm period, 8 November 2004

These figures strongly show that the phase slips caused by the storm time may be due to abrupt spatial or temporal shifts in the distribution of electron density relative to that of the quiet day that could result in loss of lock of the receiver. Geomagnetic storms and severe scintillation conditions are highly disturbed by the equatorial ionosphere and unreliable space-based navigation. Studies on the two overlapping geomagnetic storms have clearly shown the adverse effects of measuring GPS delay range. The impact of geomagnetic storms correlates to a range delay of about 15 m. In this study, the geomagnetic field effect can't be neglected in GNSS measurement (Rao, et al., 2006).

The fourth methodology measure three-Dimension Ray Tracing Computer Software for Radio Waves in the Ionosphere, known as the Jones 3-D Ray Tracing Program, can be used to determine the properties of GPS



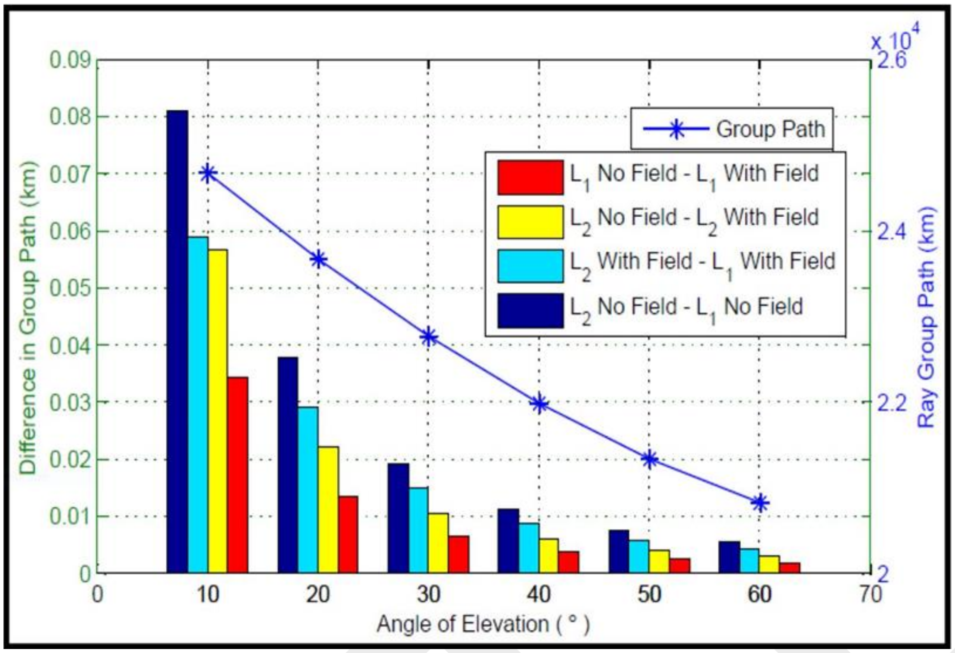


Figure 5: L1 & L2 frequency without ionospheric gradient

The direction is stronger than the field without the ionospheric gradient and the magnetic field. This implies that without an ionospheric gradient, the field has less effects on the group direction. Compared to L1, L2 takes longer pathways to spread across the ionosphere because of the influence of refraction. As the elevation angle increases, both with field and without field decrease. In the figure 5 the entire outcome for this scenario was shown. The findings of ray-tracing have shown that certain impact on final GPS positioning specifically led to this. The Earth's magnetic field and horizontal ionospheric slope significantly affect the GPS group's path. The impact is very small, but if millimeter precision level is needed inaccurate GPS positioning, it cannot be ignored (Nagarajoo & Fah, 2013).

4 CONCLUSIONS

The first research paper describes the receiver tracking performance changes due to the magnetic field effect. The variance of the error calculates receiver signal tracking performance at the PLL output and jitter variance. In this scenario, high scintillation day, GNSS signal influences the geomagnetic field. Then GNSS tracking performances change in few periods. Then the position accuracy in GNSS is decreased.

In the second research paper, which was selected, it is described how the GPS receiver performance is subjected to changes due to the geomagnetic substorms. The effect was mainly depending on electronics density in the aurora area. In high geomagnetic substorms day, observation of GPS receiver accuracy and receiver tracking performance efficiency goes down due to missed measurements during re-acquisition times. It was also proved some magnetic field effect is occurs concerning GPS observation.

The third research paper depicted the geomagnetic storm effect for GPS navigation. It was measured by phase lock-loop (PLL) in the GPS receiver. Reduce the number of GPS receiver signals locked by a consumer receiver; bad navigation accuracy was observed. Adverse effects on the measurement of the GPS delay range could also be seen. The impact of the geomagnetic storm effect is correlated to signal delay.

The fourth article noted that the researchers had used the Jones 3-D Ray Tracing program to determine GPS signals' properties due to the geomagnetic field's effects. Moreover, it was observed that the horizontal ionospheric gradient has a significant impact on the earth's magnetic field effect. This study proves that the signal effect is minimal, but if a millimeter precision level is needed for accurate GPS positioning, it cannot be ignored.

5 RECOMMENDATION

As per the findings of this study, it is recommended to consider the external and internal area's magnetic and metal item effect when using GNSS observation for land surveying and construction surveying activities. Further, it is recommended to consider the world magnetic model value relevant to the data collection area, as a practice, and to get pre-knowledge about heavy substorm and other magnetic field effect weather before starting any GNSS observation in order to harvest the maximum output with limited errors through the project.

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