Study of GPS Positional Error Near the Crest of the Equatorial Ionization Anomaly during Quite Day

Richa Trivedi

July 3, 2020

Study of GPS Positional error near the Crest of the Equatorial Ionization Anomaly during Quite Day

RichaTrivedi, Department of Physics, UIT, RGPV,
Bhopal, India

Abstract

The accuracy with which a user receiver can determine its position or velocity, or synchronize to GPS system time, depends on a complicated interaction of various factors. In general, GPS accuracy performance depends on the quality of the pseudorange measurements as well as the satellite ephemeris data. The accuracy to which the satellite clock offsets relative to GPS system time are known to the user, or the accuracy to which satellite-to-user propagation errors are compensated, are important. Relevant errors are induced by the control, space and user segments. To analyze the effect of errors on accuracy, a fundamental assumption is that the error sources can be allocated to individual satellite pseudorange values. The GPS Ionospheric Scintillation and TEC Monitor (GISTM) based GPS receiver was installed at an equatorial station, Bhopal (23.2° N, 77.4° E, Geomagnetic latitude 14.23˚ N), India in order to study GPS position error. The horizontal error, level of confidence in terms of DRMS & CEP, positional error were analyzed from fixed GPS point for 15 August 2005(Quite day). In the present paper an attempt has been made to study the GPS position errors during the quite day, the latitudinal error and longitudinal error in meter were also studied. We observed that the latitudinal error lies between 1.52 to -1.25 meter while in longitudinal error points lies between 1.97 to -1.25 meter. It was observed that most of the error points lie with in the 95% error ellipse. Due to the sufficient number of locked satellites, and in the absence of any ionospheric disturbance, the DOP parameters remained smooth for the whole day, this helps locate precise position.

Key Words: Circular error probable (CEP) Dilution of Precision (DOP) Global Positioning System (GPS).

I INTRODUCTION

Global Positioning System (GPS) receiver computes its position based on time difference of GPS satellite and user. GPS accuracy performance depends on the quality of the pseudorange measurements as well as the satellite ephemeris data. It's important to known to user the accuracy with which the satellite clock offsets relative to GPS system time, or the accuracy with which satellite-to- user propagation errors are compensated. Relevant errors are induced by the control, space and user segments. To analyze the effect of errors on accuracy, a fundamental assumption is that the error sources can be allocated to individual satellite pseudorange values. The effective accuracy of the pseudorange value is termed as user-equivalent range error (UERE). The UERE for a given satellite is considered to be the (statistical) sum of the contributions for each of the error sources associated with the satellite. UERE is usually assumed to be independent and identically distributed from satellite to satellite. The accuracy of the position/time solution determined by GPS is ultimately expressed as the product of a geometry factor and a pseudorange error factor. Dilution of precision (DOP) associated with the satellite/ user geometry is the geometrical factor which expresses the composite effect of the relative satellite/user geometry on the GPS solution error. This is expressed in a scalar quantity, which in navigation literature is termed as Dilution of Precision (DOP). The accuracy of DOP for position determination can be affected by the configuration of the satellites in view of a precision receiver. Pseudorange errors, Satellite clock error, Relativistic effects, Atmospheric effect, Ionospheric effects, Tropospheric delay, Receiver noise and Resolution, Multi path and shadowing effects are the major error sources in GPS. The bounded region as mentioned below is to study/ see in order to calculate the percentage of error in position determination i.e. DRMS is the Root Mean Square, a horizontal measure of accuracy representing the radius of a circle within which the true value lays at least 95 percent of the time.

$$DRMS=\sqrt{(\sigma_{x_u})^2+(\sigma_{y_u})^2} \qquad (1)$$

$$\mathrm{CEP}=0.589\sigma_{x_u}+0.589\sigma_{y_u} \qquad (2)$$

Where σ_{x_u} and o_{y_u} are the SD in the determination of the corresponding coordinate. 2DRMS is the twice-distance Root Mean Square. A circle of a specified radius that encloses 50 percent of the data points is defined as Circular error probable (CEP), which is a statistical measure of the horizontal precision. Thus, half the data points are within a 2DRMS CEP circle and half are outside the circle. The probability of error can be observed by plotting the circle of radius 2DRMS and CEP, the CEP indicates for 95% of positional error [8]. As GPS system became one of the important tool for variety of human activity. In this connection, much attention is given to continuous perfection of the GPS system and to the widening of the scope of its application for solving navigation problems, as well as for developing higher–precision systems for time and position determinations [15].

A variety of TEC models have been developed till date, which are intended to cancel out the ionospheric influence on the performance of the modern GLONASS and GPS under geomagnetically quiet and weakly disturbed conditions [4,9]. Geomagnetically disturbed conditions of space environment and cases of irregularities in Tec component makes the situation more complicated. The amplitude of random TEC variations with a period from a few minutes to several hours in conditions of geomagnetic disturbances can make up as much as 50% of the background TEC value [5, 16]. Furthermore, the range of amplitude and phase fluctuation of navigation satellites signals at the reception point can exceed the design level required for the uninterrupted operation of GPS receivers. Under these conditions, the accuracy to which the current location can be determined is degraded for both stationary and mobile users of GPS [2], therefore, it is necessary to have real-time analysis to provide the model that will help to correct this error. At the same time, these perturbations in the GPS signals are taken as scientific information used to investigate ionospheric scenarios. GPS receiver tracking performance can be degraded in the presence of scintillation effects [14]. [12] Investigated high latitude scintillation effects during an intense substorm event in August 1998. They observed degraded L2 phase tracking performance for periods of up to one hour, with L2 data dropouts primarily in the range 40– 200s. These results were derived using a codeless receiver. For an earlier event in 1992, [7] observed simultaneous loss of lock events on two-three satellites during one 20-minute period of intense scintillation, using an older version Ashtech P-12 receiver located near the South Pole.

The geomagnetic conditions of CHAMP during January-December 2003 was studied by [3] and they found in their study that during disturbed as well as undisturbed geomagnetic conditions, the most probable error of CHAMP positioning is less than 10 m. [6] studied the ionospheric disturbance data of a local GPS network in Hong Kong (low latitude region) during the solar maximum period (2001–2003). They studied the spatial and temporal distributions of the disturbances in Hong Kong. They found that strong ionospheric disturbances occur frequently during the solar maximum period, particularly around March and September, and concentrate at the region around geographic latitude 22°N (geomagnetic latitude 12°N). During their study the effects of disturbances on GPS geodetic receivers, such as loss of lock and measurement noise level, are also analyzed. They show that the measurement noise level and the number of losses of lock in GPS data increase dramatically during ionospheric disturbance periods and during their study behaviors of different types of GPS receivers during the disturbances are also compared. [12] analyze one-year GPS data during low solar active period year 2005. During their study they found that the average number of satellites locked is 7.194 disturbed ionosphere, and the quality of a GPS derived position estimate depends upon signal strength, ionospheric effects, multipath and many more factors which is used for the measurement geometry as represented by DOP, range errors.

By using GPS data recorded at Space Science Laboratory, Department of Physics, Barkatullah University, Bhopal, India (23.2° N, 77.4° E, Geomagnetic latitude 14.23° N), we have studied the cases of GPS position error during 15 August,2005 in the present paper .

II DATA AND METHOD OF ANALYSIS

In order to study GPS position error at an equatorial station, Bhopal (23.2° N, 77.4° E, Geomagnetic latitude 14.23° N), India the GPS Ionospheric Scintillation and TEC Monitor (GISTM) based GPS receiver was installed. The horizontal error, level of confidence in terms of DRMS & CEP and positional error from fixed GPS point, which is mounted on the roof of the Space Science Laboratory, Bhopal was analyzed GPS data have been surveyed for year 2005-2006 in various ionospheric conditions , in order to eliminates each possible error in positioning. Out of various cases in the present paper I am studying for August 15, 2005 (quite day of low solar activity period). Vertical TEC(VTEC)is obtained by taking the projection from the slant to vertical using a thin shell model, assuming a height of 350 km following the technique given by [9] is used in order to study the effect of the ionosphere on the GPS receiver.

$$\text{Vertical TEC (VTEC)} = \text{STEC x Cos (arc Sin (} \frac{R_e Cos\theta}{R_e + h_{\max}} \text{))} \qquad (3)$$

The error of conversion from STEC to VTEC is minimized for the elevation angle greater than 30 deg. in the Indian region for 350Km height of ionospheric shell, therefore average VTEC values were obtained by averaging every 15-minute values of VTEC for PRNs having elevation angle $\geq 30^{\circ}$. With the help of Equation no. 1 and 2 CEP, 2DRMS, Horizontal Error, and satellite geometry have been calculated in-order to analyze the effect of VTEC on positioning [13,15].

III RESULT, DISCUSSION AND CONCLUSIONS:

In the present paper an attempt has been made to study the position error during quiet ionospheric conditions. The Dst, Kp index, VTEC, 2DRMS, number of satellite and PDOP for an ionospherically quiet day, on Aug 15, 2005 is shown in Figure 1(a) to 1 (e). The Dst was very quiet on this day, and reaches to highest positive value of up to 18 nT at around 1300UT and during the period of study it remain positive, and the Kp index was 1 around 0900 UT then starts increasing and reach to 2.3 around 1500 UT (Figure 1 (a)-(b)). Ap reached to 7 and Sun Spot Number (SSN) was 27. During the period of study the VTEC having the highest value ~ 36 TECU at around 1030 UT, then decrease to 26 TECU at 1230 UT, then again increase and reach to 29 TECU at 1310 UT, which represents the quiet state of ionospheric activity and has also been crossed checked with Dst and Kp index(Figure 1 (b)-(c)). During the period of study we observed that at around 1000 UT number of satellite locked was 10 and during that time 2DRMS was 0.58 m and PDOP having the value 0.8, then number of satellite dropped and at 1100 UT number of satellite locked was 08, 2DRMS was 0.27 m, PDOP was 1 and around 1130 UT number of satellite locked increases to 09, 2DRMS was 1.24 m, PDOP was 0.8. The 2DRMS reaches to highest value 2.0 m at around 1315 UT during the time PDOP was 1 and number of satellite was 09 (Figure 1(d)-(e)).

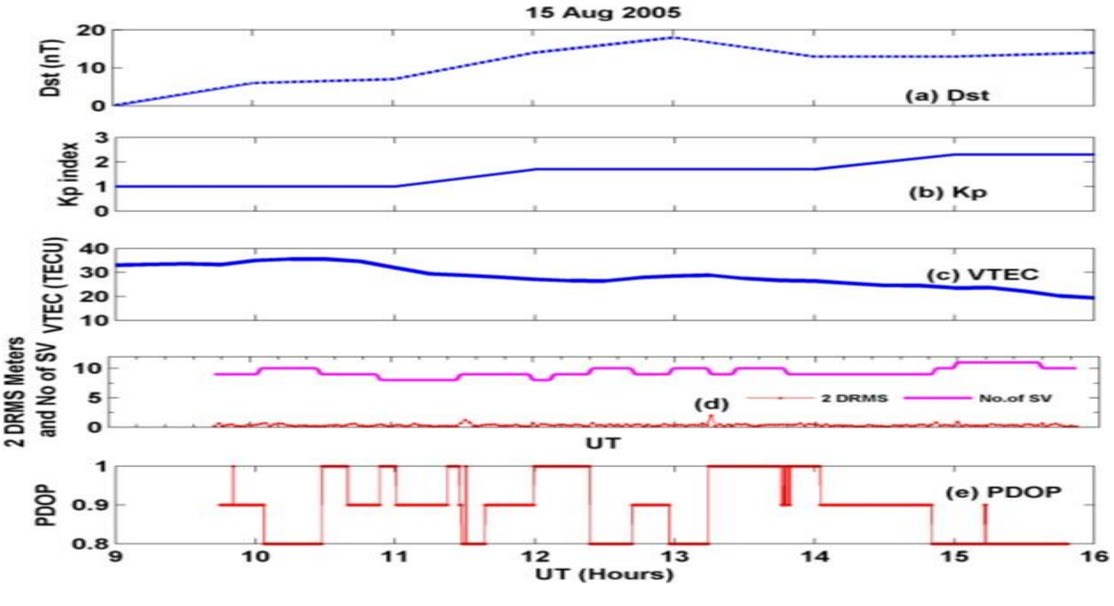

Figure 1: **Variation of (a) Dst, (b) Kp index, (c) VTEC, (d) 2DRMS and No. of SV, (e) PDOP for August 15, 2005.**

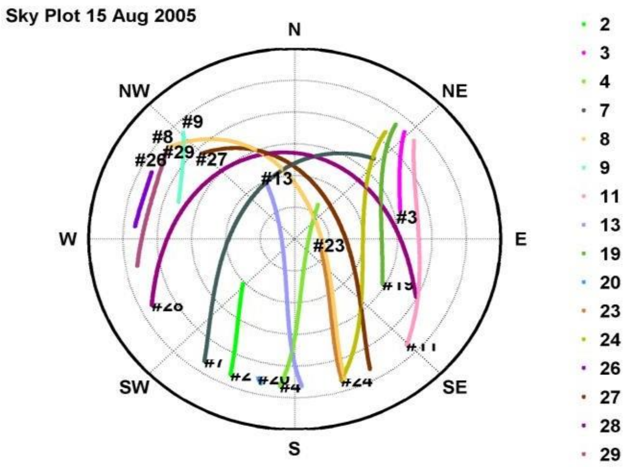

Figure 2: **Sky plot of August 15, 2005 for 1000 to 1600 UT. # Sign followed by the number shows the starting point of the satellite for the specific period.**

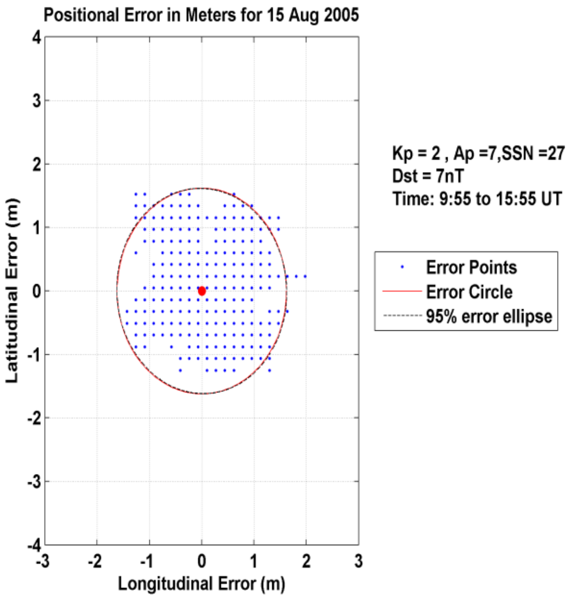

Figure 3: Position error for August 15, 2005(quiet day), Both Errors circle and 95% error ellipse coincide in this case.

Figure 2 shows the Sky plot of satellite locked during the period of 01000 UT to 1600 UT, while Figure 3 shows the Latitudinal error and longitudinal error in meter during quiet day form 0955 UT to 1555 UT. Looking to the sky plot it is observed that satellite geometry was well enough. No Loss of lock and scintillation effect has been observed during the period of study. We observed that the maximum number of error points in the latitudinal error lies between 1.52 to -1.25 meter while in longitudinal error points lies between 1.97 to -1.25 meter. It was observed that the error points are distributed in all direction, and two to three latitudinal error and longitudinal error points lie outside the circle but rest of the error points lies inside the 95% error ellipse and it is observed instead of ellipse the error point and 95% error ellipse formed a circle and both of them coincide with each other. The main factors affecting DOP are the number of satellites being tracked and where these satellites are positioned in the sky The DOP parameters remained smooth for the whole day because of sufficient number of locked satellites, thus the above graph shows that the precise position.(i.e. very less position error) is obtained in the above mentioned quite day. The precise position may be due to absence of any ionospheric and local atmospheric disturbance. Hence we can conclude that number of satellite locked and geometry of satellite plays a vital role in studying the position error

In geomagnetically disturbed conditions of geo-space the accuracy and quality of GPS performance is impaired. Unlike geomagnetically quiet conditions, magnetic storm conditions are accompanied by an increase in the spherical standard deviation in the position determination for all types of GPS receivers. Now days the satellite navigation GPS system has become an important and powerful factor of scientific and technological progress worldwide, and widely use in a great variety of human activity. In this connection, much attention is given to continuous perfection of the GPS system and to the widening of the scope of its application for solving navigation problems, as well as for developing higher–precision systems for time and position determinations [8]. The presence of ionospheric irregularities can cause degradation in the GPS navigational accuracy and limitations in the GPS system tracking performance. Under high levels of ionospheric activity, the ionospheric range error can dominate the GPS error budget and can cause degradation of GPS receiver tracking performance and, in extreme cases, loss of navigation capabilities. Essentially, free electrons contained in the ionosphere affect the propagation of the signal as it passes through. Since the signals are travelling at the speed of light and GNSS is based on nanosecond timing, it does not take much interference to introduce error.

ACKNOWLEDGMENT

The authors wish to thank SPIDR Data Centre for providing the data. Dst data are downloaded from World Data Centre, Kyoto University web site (swdcwww.kugi.kyoto-u.ac.jp), Kp and Ap Index are downloaded from Space Physics Interactive Data Resource (SPIDR) web site (http://spidr.ngdc.noaa.gov/spidr).

5 REFERENCES:

[1] Afraimovich E L, Altyntsev A T, Grechnev V V, Leonovich L A, (2001c), Ionospheric effects of the solar flares as deduced from global GPS network data. Adv. Space Res., 27, 1333-38.

[2] Afraimovich E L, Demyanov V V, Kondakova T N, (2003), Degradation of performance of the navigation GPS system in geomagnetically disturbed conditions. GPS Solutions, 7(2),109-119.

[3] Afraimovich E L, Demyanov V V, Tatarinov P V, Astafieva E I, Zhivetiev I V, (2006), GPS Users Positioning Errors during Disturbed Near-Earth Space Conditions. In Characterising the Ionosphere Meeting Proceedings RTO-MP-IST-056, Paper 29.Neuilly-sur-Seine, France: RTO, 29, 1 -14.

[4] Afraimovich E L, Lesyuta O S, Ushakov I I, (2002*a),* Geomagnetic disturbances and functioning of navigating system GPS, Geomagnetism and Aeronomy, 42(2), 220-227.

[5] Bhattacharrya A, Beach T L, Basu S, Kintner P M, (2000), Nighttime equatorial ionosphere: GPS scintillations and differential carrier phase fluctuations, Radio Sci., 35, 209-224.

[6] Chen Wu et al., (2008), Effects of ionospheric disturbances on GPS observation in low latitude area, GPS Solutions, 12, 1, 33-41.

[7] Clynch J and Henry C, (1994), Ionospheric effects on GPS and DGPS in polar regions, Proceedings of the ION GPS-94, Salt lake City, Utah.

[8] Kaplan E D, (1996), Understanding GPS Principles and Applications, Artech House Boston, London, 1-533.

[9] Klobuchar J, (1986), Design and characteristics of the GPS ionospheric time-delay algorithm for single frequency users, in: Proceedings of PLANS' 86 – Position Location and Navigation Symposium, Las Vegas, Nevada, 280–286.

[10] Klobuchar J, (1996), Ionospheric effects on GPS. In: Parkinson BW and Spilker JJ. (Eds). Global Positioning System: theory and applications. American Institute of Aeronautics and Astronautics Inc.: Washington.

[11] Nichols J, Hansen A, Walter T, and Enge P, (1999), High latitude measurements of ionospheric scintillation using the NSTB, Proceedings of the ION National Technical Meeting, San Diego, California.

[12] Skone S H, (2001), The impact of magnetic storm on GPS receiver performance. J Geodesy., 75(6), 457-468.

[13] Tiwari R, Bhattacharya Soumi , Purohit P K, and Gwal A K, (2009), Effect of TEC Variation on GPS Precise Point at Low Latitude The Open Atmospheric Science Journal,3, 1-12.

[14] Warnart R, (1995), The study of the TEC and its irregularities using a regional network of GPS stations, IGS Worksh Proc, 249-263.

[15] Trivedi R ,(2017), Study of GPS Position Error during 16 June, 2005 (Disturb Day) at Bhopal, Circulation in Computer Science,1-4,2017.