STUDY OF CYCLE SLIPS AND SIGNAL TO NOISE RATIO IN DUAL FREQUENCY GPS RECEIVER

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ABSTRACT

The applications of Global Positioning System (GPS) are increasing rapidly in every area and the requirement for precise navigation is becoming more important. The positional accuracy of GPS is affected by many factors including clock biases and atmospheric delays; of these the ionospheric delay is significant. Inversely, GPS has also become an important tool to study various parameters of the atmosphere. The ionospheric irregularities produce scintillations at the GPS receivers in both amplitude and phase that cause cycle slips and even loss of locks. The severity of the ionospheric scintillation is measured from the S4 index derived from the signal to noise ratio. Here in this paper we present the role of ionospheric irregularities in affecting the signal to noise ratio at the receiver that causes cycle slips.

KEYWORDS: *Ionospheric scintillations, cycle slips, atmospheric delays, irregularities*

I. INTRODUCTION

The Global Positioning System (GPS) is a satellite-based navigation system, which provides accurate position, velocity and time information to the user globally and continuously under all weather conditions. There are many factors that affect the positional accuracy of the GPS receiver like clock biases of satellites and receiver, receiver noise, and satellites and atmospheric delays etc[8]. Though GPS radio signals are subjected to various atmospheric effects, which degrade its accuracy in all three layers of the atmosphere (troposphere, stratosphere, ionosphere), the effects of accuracy degradation in the ionosphere are the most significant. The ionosphere, as the name implies, is that region of the atmosphere, which contains a large number of ionized molecules and a correspondingly high number of free electrons. The ionosphere is a dispersive medium, which means it bends the rays of the GPS signal (refraction) and changes its speed as it passes through the various ionospheric layers to reach a GPS receiver. Bending the GPS signal path causes a negligible error if the satellite elevation angle is greater than 5 degrees. But the group delays introduced by ionospheric total electron content (TEC) and ionospheric irregularities [Wanninger, 1993] are the major factors.

The low latitude ionosphere in particular, poses a challenge to both GPS users and Satellite-Based Augmentation System (SBAS) providers. Single and dual frequency GPS receivers used in low-latitude regions can suffer from rapid amplitude and phase fluctuations known as scintillation [Seybold, 2005; Wanninger, 1993]. Scintillation occurs when the GPS or SBAS satellite signal traverses through small-scale irregularities in the ionospheric electron density, which occurs typically during evening and night time in equatorial regions. Intense scintillations and high rate of change in TEC [1, 2] can cause loss of lock in dual frequency and single frequency GPS receivers. At these times, GPS users in low latitudes can experience decreased levels of accuracy and confidence in stand-alone positioning. Multipath can also inflate S4, falsely indicating ionospheric scintillation activity, and is removed with the use of a multipath/scintillation discriminating technique [3].

In this paper, we study the cycle slips of the dual frequency receiver, correlating with scintillations and signal to noise ratio (C/No). Through these irregularities [4] when intense cause cycle slips, but in some cases these irregularities lead to loss of locks if scintillations are for longer period[5,6,7]. Cycle slip is a phenomenon in which it is a loss of integer number of cycles at receiver. Cycle slips can be identified from drastic changes in the pseudo-ranges or by the inspection of changes in the derived parameters like total electron content (TEC) and C/No ratio.

II. DATA COLLECTION

The TEC data of dual frequency receiver's data from International GNSS Service (IGS) stations is obtained for this analysis, from the webpage of National Oceanic and Atmospheric Administration (NOAA) for a period of 15 months from October 2004 to December 2005[9]. The data NOAA gives a near real time TEC data at interval of every 15 minutes.

To conform our predictions on GPS data from Scripps Orbit and Permanent Array Centre(SOPAC)[10] where data is collected from 4 IGS stations around equator they are, AREQ (geographic 18 N Lat, 75° E Long, geomagnetic 9.24° N lat), FORT (geographic 5° N lat, 38° E long, geomagnetic 1.44° N lat), GLPS (geographic 0° N lat, 90 E long, geomagnetic 9.73° N lat), HOUR (geographic 8° N, 53°E long, geomagnetic 2.03° N lat) on these days which are in RINEX (Receiver Independent Exchange) format.

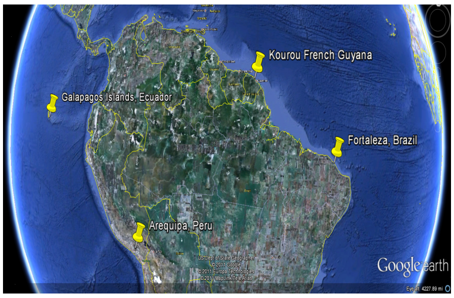

Figure-1: Four IGS stations AREQ, FORT, HOUR, GLPS in South America

RINEX data is converted to data files by a program developed by us through which satellite PNR, time of appearance, position, dual frequencies, TEC will be determined. We can confirm that is a cycle slip by using more parameters rather than single TEC or C/No data. So by observing TEC, L1, S4 index and elevation angle parameters we can strongly conform cycle slip has occurred. Pseudo S4 indexes are calculated from C/No data at L1 signal [11~15].

III. OBSERVATION OF CYCLE SLIPS

3.1 ON 7th NOV 2004:

On this day, these heavy scintillations are caused due to the coronal mass ejections (CMEs). These CMSs are emitted from sun it has taken two days to reach earth by 7th Nov 2003 and the effect last for 67 min's (02:42:56 to 3:49:50). These emissions were observed by NASA to days before the event, it is observed that relative shocks were observed two days after the emissions of solar ejections and these shocks are related as type-II burst-associated shock waves in corona, solar wind and magnetic clouds at 1AU. There are three CME events: (1) produce significantly enhanced level of turbulence in the inner heliosphere, (2) decelerate rapidly with heliospheric distance, and (3) produce intense shock at 1AU We observed heavy depletions in midnight duration this was clearly observed using L1(C/No) data and elevation angle. First plot explains the sudden depletions in TEC content, these dips has reached a minimum of 12 TEC units from 38 TEC units and second plot will explain occurrence of cycle slip, in which heavy variations in TEC, L1-signal are high than S4-Index, this data was collected form IGS station from Arequipa, Peru.

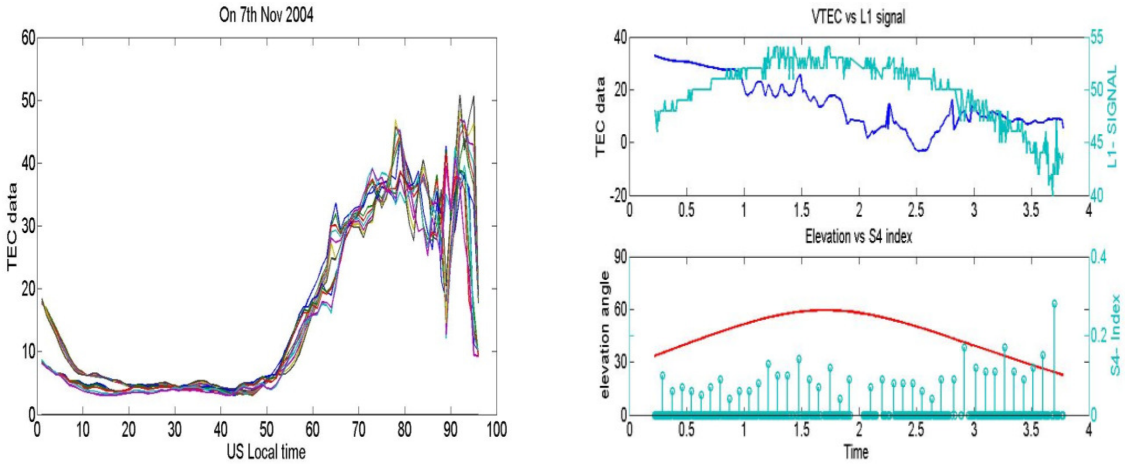

Figure-2: TEC data from NOAA on 7th Nov 2004

3.2 ON 8th NOV 2004:

On this day cycle slip is caused due to upward drift of gradual buildup of zonal winds of solar storms. The signal irregularities was mainly observed on ground to satellite radio signals for a duration of 35 min's(01:13 to 01:43) in the early hours of 8th Nov 2004. These heavy scintillations were mostly observed over Brazilian region and heavy vibrant movements were observed in many satellite signals. This ionospheric storm period has an isolated rapid signal fading as shown in TEC plot. We find depletions of data with respect to L1-signal (C/No), TEC content and S4 index in second plot, though for a small duration of time but this counts in navigation and data is collected from Arequipa, Peru.

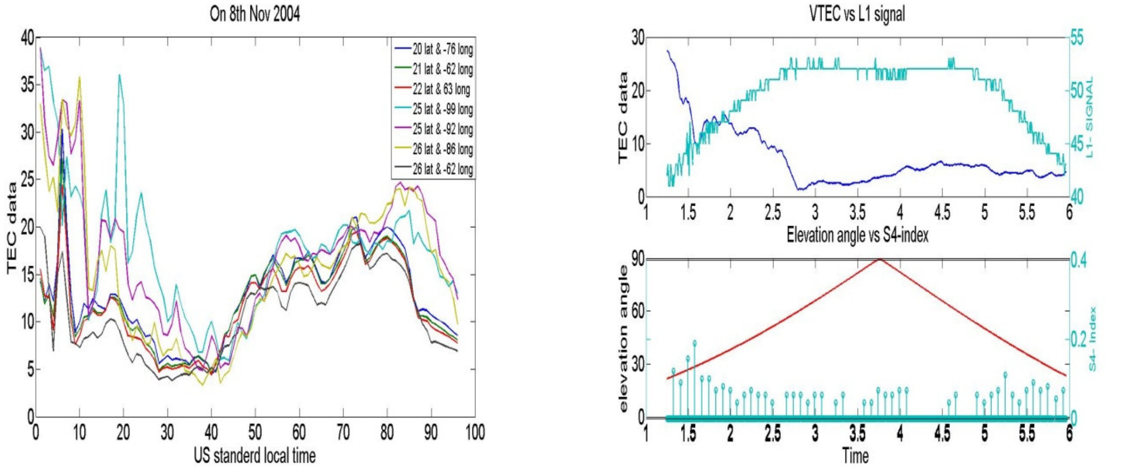

Figure-3: TEC data from NOAA on 8th Nov 2004

3.3 On 9th Nov 2004:

On this day a large magnetic storms were observed across the world epically in northern hemisphere of earth. It is observed that these magnetic storms has a largest upward drift of 120m/s and has relative east word electric field of magnitude off 3m/s in early hours of day of Brazilian sector and in mid latitudes regions. By this effect large F region plasma is uplifted on the dayside due to eastward magnetic field, and large F region plasma is down lifted on night side due to westward electric field. This effect is observed for an hour all over the word and depletions were observed less than an hour about 52 min's (00:38 to 01:30). Variations were clearly observed in TEC content in plot-1, in which a depletion of 30 TEC units was observed. In second plot L1-signal (C/No), S4-index variations are high and data is collected from Kourou IGS station in French Guyana.

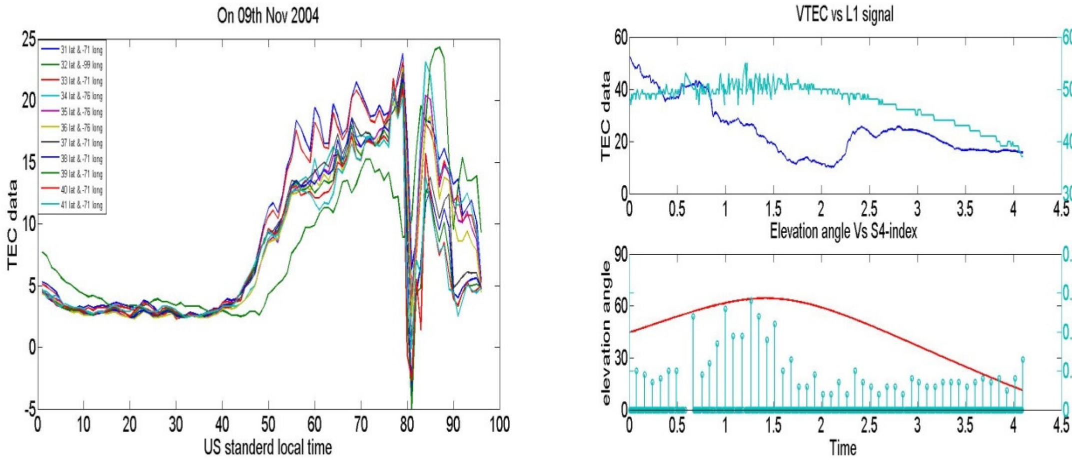

Figure-4: TEC data from NOAA on 9th Nov 2004

3.4 On 18th Jan 2005:

On this day a sever geomagnetic storms has been detected over the earth. The ionospheric density and composition experience significant changes both globally and locally during these geomagnetic storms observed for duration of 90 min's (02:10 to 03:40). In the premidnight period, the eastward electric field is enhanced and consequently, the F-layer along with the irregularities formed at the bottom of the F-layer is lifted upwards. Cycle slip was observed by using all 4 parameters as shown below figure. We can see heavy depletions on TEC values a dip of 56 TEC units were detected. Similarly on other parameters the variations were very random in TEC, L1-signal, and S4-Index parameters and data is collected from Fortaleza IGS station, Brazil.

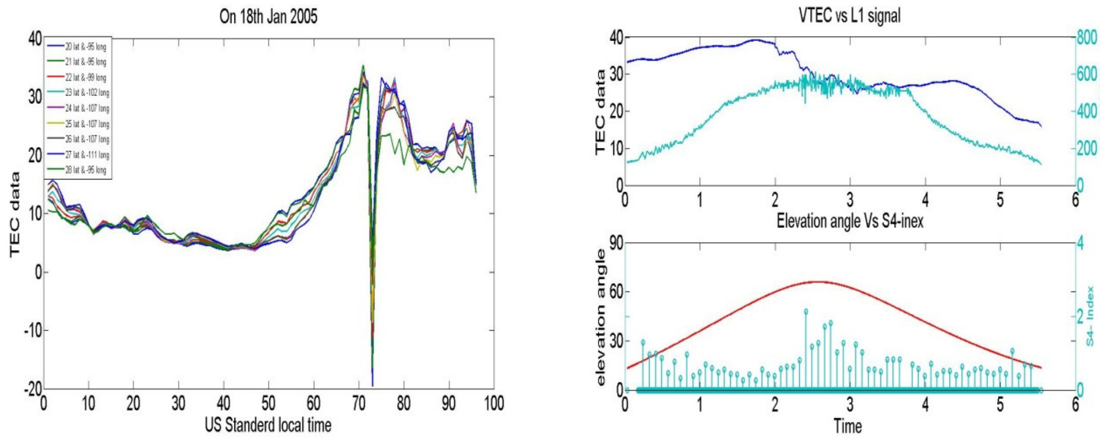

Figure-5: TEC data from NOAA on 18th Jan 2005

3.5 On 18th July 2005:

On this day, ionospheric scintillations are caused due to Fast narrowband VLF perturbations which produce an ionization changes in the D region resulting a heavy thunderstorm. The raise in temperature of ionospheric electrons is caused by the electromagnetic pulse (EMP) from lightning (in a manner similar to that which produce fast optical emissions called elves), it occurred at 70 -85 km above ground and it is observed for a duration of 35 min's (04:35 to 05:10 am). Much depletion was observed in different time zones, especially in early morning hours where all the parameters were affected during scintillations. These fluctuations are clearly seen in plots especially in L1-signal and S4-Index parameters, this data is collected from Galapagos Islands, Ecuador.

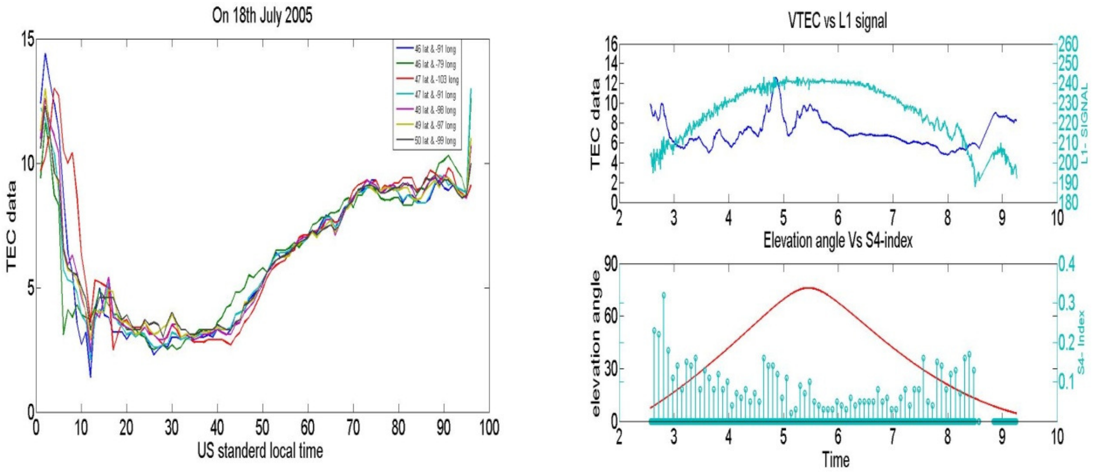

Figure-6: TEC data from NOAA on 18th July 2005

3.6 On 7th Sept 2005:

On this day, differential solar proton flux which is like solar wind, plasma drift and ionospheric absorption was observed in the morning hours of the day. An events of Interplanetary Coronal Mass Ejection (ICME - 1AU) has been recognized which is superimposed on the Interplanetary Magnetic Field behaviour (IMF). It is observed for duration of 55 min's overall from time 3:40 to 3:50 and 04:45 to 05:40 in which an intense solar flares were observed, a strong E region electron density enhancement was observed as a result, it leads to an unusual phenomenon that the E region electron density exceeds the F region electron density and this situation is continued for next two days. In the early hours of day time these depletions were observed, we can observe all parameters variations like TEC, L1-signal (C/No), elevation angle and S4-index in the plot, especially in TEC and L1-signal at different time during observation of scintillation and data for this plot is collected from Arequipa Peru.

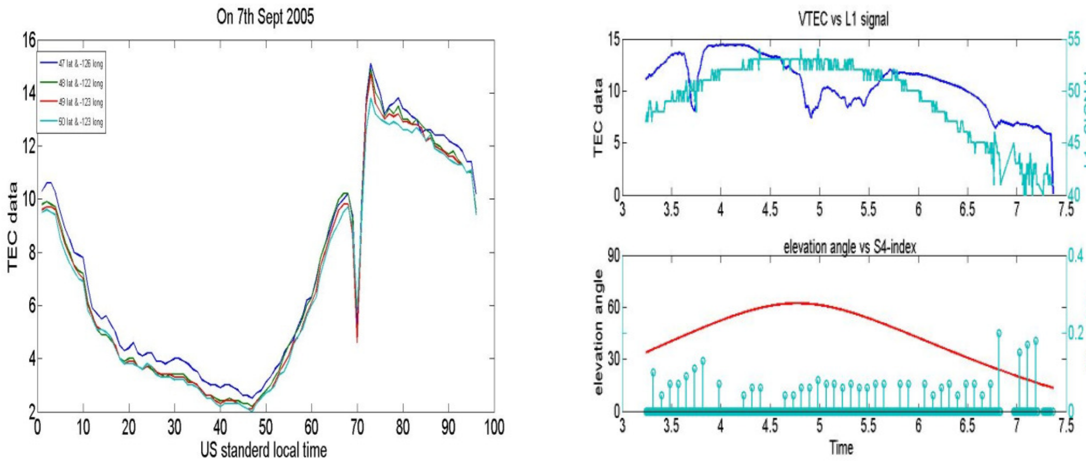

Figure-7: TEC data from NOAA on 7th Sept 2005

3.7 ON 22nd DEC 2005:

Equinoxes is main cause for this cycle slip activity. These scintillation activities are caused due to the Equatorial Anomaly and also due to longitudinal dependency, these scintillations are more common in South America than any other region in the world and it is observed for duration of 10 min's (09:10 to 09:20). On this day, a large depletion of TEC was observed in TEC content, in TEC, L1-signal (C/No) and S4-index plot also we can find depletion mainly in TEC, S4-Index values, this depletion was observed in morning session at 9:15 min of local time, data is collected from Arequipa Peru.

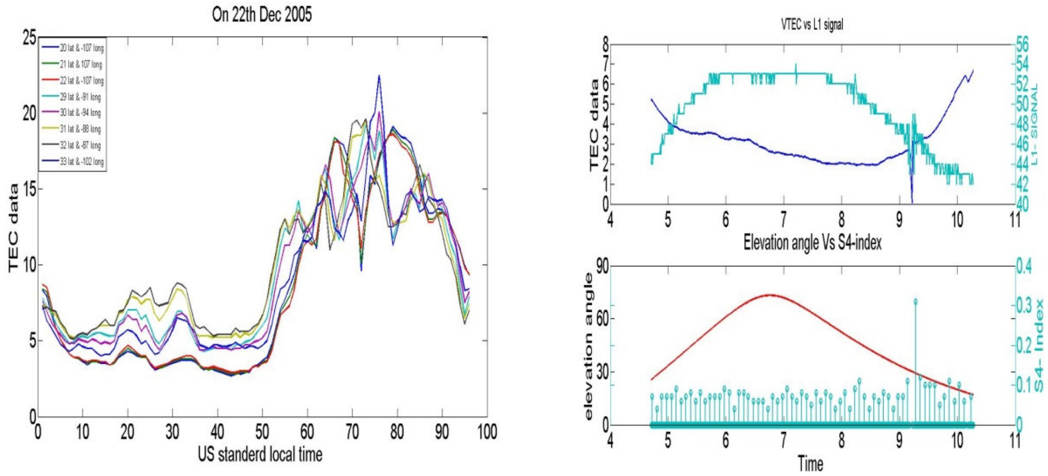

Figure-8: TEC data from NOAA on 22nd Dec 2005

IV. RESULTS AND DISCUSSIONS

Data from NOAA and SOPAC IGS stations are taken for depletion analysis. We have collected TEC data from NOAA, and plotted are as shown in first plot of each figure, to conform our predictions on cycle slip data from SOPAC IGS stations are collected in RINEX format to develop positioning and frequency values using a program developed for reading RINEX formatted GPS data http://seemala.blogspot.com/. In the second plots has details on TEC data, L1 (C/No) data, elevation angle and S4 index parameters were shown. Comparison between different GPS parameters for detecting cycle slip is shown in below table.

In considering NOAA data TEC depletions (DIP) are observed with a dip of minimum of 15-20 TEC Units. Fortunately a very few cases were observed as 2004 and 2005 which are in descending phase of solar activity.

Table-1: Parameters observed from NOAA (TEC-Obs), SOPAC (TEC, L1-signal, S4-Index)

Date	TEC dip Observed (TEC Units)	TEC Diff (TEC Units)	L1-Signal (db)	S4-Index	Cycle slip Duration (min's)w.r.t TEC dep
7th Nov 2004	36	12	3.5	0.1	67
8th Nov 2004	23	8	6	0.1	35
9th Nov 2005	23	20	8	0.2	52
18th Jan 2005	53	5	12	0.1	90
18th July 2005	11	6	2	0.1	35
7th Sept 2005	5	8	5	0.13	55
22nd Dec 2005	12	3	6	0.2	10

Here data is analysed for detecting the cycle slips. Plots with more dip compared to other are sorted out for estimating the cycle slip. On the days where heavy depletions were observed, on those days RINEX formatted data is collected from SOPAC IGS stations receivers, where RINEX formatted data is extracted using a program has been developed which gives position details, TEC, angles, and other parameters like satellite frequencies. By using this data we plotted figure having TEC value, L1 (C/No) data on single window and S4-index and elevation angle on other window. This is to conform that cycle slip has occurred at that particular location. To verify depletion of scintillations on GPS signals first TEC was observed, later L1-signal (C/No) was also plotted. After conforming the depletions elevation angle and S4-index were also plotted to stress that depletions occurred are cycle slip.

The S4 index, which is a measure of the amplitude scintillation over one minute, does not characterise fades of short duration. Nevertheless, such fades are present in the raw data, and have an adverse effect on the reliability of a signal link S4-index was calculated and plotted for every 5min gap with below equation.

$$S_4 = \sqrt[2]{\frac{E(\sum I^2)}{E(\sum I)^2} - 1}$$

L1-signal is direct SNR/(C/No) value directly obtained from received signal. Elevation angle is look angle of IGS receiver station of GPS satellite.

V. SUMMARY

Detection and correction of cycle-slips is important to all applications using carrier-phase information. Cycle slips often associated with high ionospheric dynamics and ionospheric irregularities, also with multipath affected areas with buildings where precise navigation is of special importance. Detection of cycle-slips can reliably be performed using information derived from measurement redundancy and a priori information about the receiver and its clock. For real-time applications repair of cycle-slips is of utmost importance, necessitating the use of information external to the GPS system.

GPS data over American sector is collected from large data base of NOAA and SOPAC derived electron density profiles of ionosphere/plasma sphere electron density distribution are a valuable data source for the international scientific community. The obtained space based GPS measurements contribute to a better understanding of solar-terrestrial relationships.

REFERENCES

[1] John S. Seybold, "Introduction to HF Radio Propagation", Hardcover: 352 pages, IPS radio and space service, September 2005.
[2] Clynch, J.R. (2001) "Ionospheric Bending of Radio Signals: A rough, Shell Model Approximation", published as part of Professor Clynch's collection of technical notes available athttp://clynchg3c.com/Technote/Tnotes.htm.
[3] Z. G. Elmas, M. Aquino, H. A. Marques, and J. F. G. Monico, ":Higher order ionospheric effects in GNSS positioning in the European region", Ann. Geophys., 29, 1383–1399, 2011.
[4] Doherty, P., "Ionospheric Scintillation Effects in Equatorial and Auroras Regions," ION GPS 2000, Salt Lake City, Utah, p. 662-671.
[5] W. Dean Pesnell, ''PREDICTIONS OF SOLAR CYCLE 24'', Solar Cycle 24, May 24 2007.
[6] U. Reanna, B. Rama Murthy. Et.al.., ''study of ionospheric irregularities over near equatorial station anantapur using vhf scintillation'', IET-UK International Conference on Information and Communication Technology in Electrical Sciences(ICTES 2007), Dec. 20-22, 2007. pp. 980-985.
[7] S. Banville, R. B. Langley et. al., ''Handling cycle slips in GPS data during ionospheric plasma bubble events'', RADIO SCIENCE, VOL. 45, RS6007, pages 446-460, oct 29th 2010.
[8] P. M. Kintner, B. M. Ledvina, and E. R. de Paula, ''GPS and ionospheric scintillations'', SPACE WEATHER, VOL. 5, pages 260-283, 10th Oct 2007.
[9] www.sopac.ucsd.edu/cgiin/dbDataBySite.cgi
[10] www.ngdc.noaa.gov/stp/IONO/USTEC/products/rinex
[11] P.K.Bhuyan,Rashmi Rekha Borah,"TEC derived from GPS network in India and comparison with the IRI,"Advances in Space Research vol.39, New York:Elsevier,2007,pp.830-840.
[12] Zhizhao Liu, "Ionosphere tomographic modelling and applications using global positioning system (GPS) measurements", PH.D dissertation, Univ. Calgary, Calgary,Canada, 2004.
[13] Knight,M., M. Cervera and A. Finn, "A comparison of predicted and measured GPS performance in an ionospheric scintillation environment, in proc. ION GPS,1999, pp.1437-1450.
[14] Kleusberg, A, "The Global Positioning System and Ionospheric Condition", Solar Prediction-IN Workshop, Ottawa,Canada, NOAA/Dept. of Commerce Pub.,Vol.1,PP.142-146,1993.
[15] Doherty, P.H.,T Dehel, J.A.Klobuchar, S.H.Delay, S.Datta-Barua, E.R.de Paula and F.S. Rodrigues, "Ionospheric effects on low- latitude space based augmentation system," in proc. ION GPS ,2002, pp.1321-1329.

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