Atmospheric Delay Estimation and Modeling for Precise GPS Positioning

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Abstract— To Estimate the Atmospheric delay using Ionospheric delay and Tropospheric delay, and modeling the Atmospheric delay from the Ranging equation to get the accurate Global Positioning System (GPS) positioning for Indian Institute of Science (IISC) site, Bangalore, Karnataka, India which is located at Lat/Long: $13.05^0/77.57^0$ for 6:00 hour Epoch of 1st August 2012.

Index Terms— Global Positioning System, Indian Institute of Science, Linear Free Combination Algorithm, Pseudo Random Codes, Pseudo Range, Saastamoinen Dry Delay, Saastamoinen Total Delay, Saastamoinen Wet Delay, Total Electron Content.

1 INTRODUCTION

Among various kinds of error factors, the GPS signal delay by the Atmospheric Errors is the greatest after the elimination of selective availability. The Atmospheric Delay is the sum of both Ionosphere and Troposphere Delays [1]. Hence to obtain the precise GPS positioning, it is necessary to estimate the Ionosphere and Troposphere parameters such as Total Electron Content (TEC), Ionosphere Delay, Troposphere Wet and Dry Delay. With available different modeling methods we can reduce the error in range. Hence in this paper, Atmospheric delay is estimated and corrected for precise GPS positioning.

2 GPS OBSERVABLES

They are two types of observables in GPS measurements. i.e. code range measurements and carrier phase measurements.

2.1 Carrier Phase Measurements

The carrier phase measurement is the difference in phase between the carrier waves L1 and L2 units in cycles from the satellite and the receiver oscillator signal at a specified epoch. The range is simply the sum of the total number of full carrier cycles between the receiver and the satellite multiplied by the carrier wavelength. The ranges determined by the carriers are more accurate than those obtained by the codes, But in carrier phase measurements the carrier signals are highly influenced by noise as compared to the pseudo random codes. So, we are estimating the range using code range measurements other than carrier phase measurements

2.2 Code Range Measurements

The PRN codes transmitted by a satellite are used to determine the pseudo range PR1 and PR2 units in meters or distance between the satellite antenna and the antenna of the GPS receiver. The receiver can make this measurement by replicating the code being generated by the satellite and determine the time offset between the arrival of a particular transition in the code and the same transmission in the code replica.

3 ERROR BUDGET

The GPS signals are degraded due to several factors such as atmospheric refraction, multipath, receiver clock bias, satellite clock bias and satellite-receiver geometry. Table 1 represents the typical error value for each of the error source.

From Table 1, it is clear that, error due to Atmospheric error sources are more than (≈7m) hence to obtain the precise GPS positioning, it is necessary to estimate the Atmospheric delay.

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Error Type	Error in (meters)	Segment
Ephemeris	3.0	Signal-In-Space
Clock	3.0	Signal-In-Space
Ionosphere	5.0	Atmosphere
Troposphere	2.0	Atmosphere
Multipath	1.4	Receiver
Receiver	0.8	Receiver

Table 1 GPS ERROR BUDGET

4 RANGING EQUATION

The Ranging equation is used to calculate the distance between Satellite and GPS receiver and the measured pseudo range is available in the arrived GPS signal with including all delays generated by error sources. By using the pseudo range value we can calculate the true range between GPS satellite and the Tracking station [2].

$$p = \rho + c(dt - dT) + d_{ion} + d_{tro} + \varepsilon --- Eq(1)$$

Where

'p' - Measured Pseudo Range.
'ρ' - Geometric or True Range
'c' - Speed of Light.
'dt' - Satellite Clock Offset
'dT' - Receiver Clock Offset
'd_{ion}' - Delay due to Ionosphere Region.
'd_{tro}' - Delay due to Troposphere Region.
'ε' - Effects of Multipath and Receiver measurement noise

To know the contribution of Atmospheric Delay in ranging equation we have to exclude all other error delays. Then the Eq (1) is reduced and rewritten as

$$p = \rho + d_{ion} + d_{tro} --- Eq(2)$$

After estimation of ionosphere and troposphere delays we can model the range equation using Eq.3

$$\rho = p - (d_{ion} + d_{tro}) --- Eq(3)$$

5 ESTIMATION OF ATMOSPHERIC DELAY

The GPS Signal transmitted from satellite passes through different layers of the atmosphere such as Ionosphere and Troposphere while reaching the Receiver placed on the ground. Due to the refraction of these atmospheric layers, GPS signal is delayed before it reaches the receiver.

The Ionosphere and Troposphere are two regions which are the contributors of Atmospheric Delay, but the major contributor is Ionosphere layer.

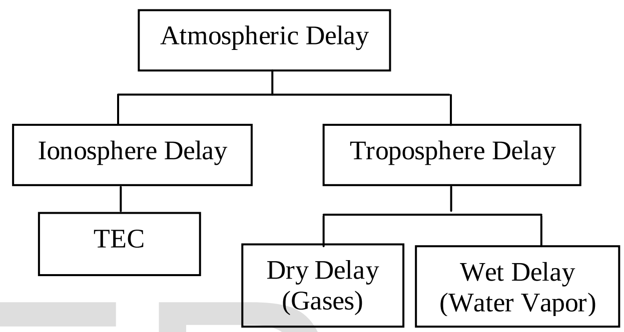

Fig (1) Atmospheric Delays

5.1 IONOSPHERIC DELAY ESTIMATION

The Ionosphere layer is full of charged particles and the delay of the GPS signal is a function of these charged particles. To represent these charged particles, we use a term called Total Electron Content (or) Count (TEC). TEC is the total number of free electrons present along a path between satellite and GPS. TEC is strongly affected by solar radiation [3][4].

The TEC can be estimated using Linear Free Combination Algorithm (LFCA), which uses Dual frequencies (f_1 and f_2).

The formula for calculating the TEC is given below

$$TEC = \frac{1}{40.3}\left[\frac{1}{f_1^2} - \frac{1}{f_2^2}\right]^{-1} \left|(pr_1 - pr_2)\right| --- Eq(4)$$

'f_1' = 1575.42 MHz
'f_2' = 1227.60 MHz

$'pr_1'$ And $'pr_2'$ Are the Pseudo Random Noise (PRN) codes (C/A and P codes)

The TEC units are in el/m^2

TEC Values are often represented in terms of Total Electron Content Units (TECU)

Where

$$1TECU = 10^{16} el/m^2$$

Ionosphere Delay Error results in meters

$$d_{ion} = \left(\frac{40.3}{f^2}\right) TEC --- Eq(5)$$

Using TEC ,Ionosphere Range Delay for f1 and f2 frequencies be estimated using Eq.5

Ionosphere Delay Error For f_1

$$d_{ion,L1} = \left(\frac{40.3}{f_1^2}\right) TEC --- Eq(6)$$

Ionosphere Delay Error For f_2

$$d_{ion,L2} = \left(\frac{40.3}{f_2^2}\right) TEC --- Eq(7)$$

5.2 TROPOSPHERIC DELAY ESTIMATION

The Error generated by Ionosphere layer is dependent on frequency but the error generated by troposphere layer is independent on frequency.

The main for generating troposphere delay is neutral atoms, water vapor and some other gases in the atmosphere.

Troposphere delay is estimated using Saastamoinen zenith Troposphere model. According to him troposphere delay is based on dry and wet part of the troposphere layer and he designed a model for estimating the troposphere delay according to his troposphere model wet part is extended up to 12km from the surface of the earth and dry part is extended up to 50km from the wet region.

Troposphere Delay estimation is based on meteorological parameters i.e (pressure, water vapor and temperature). By using the MET data Dry part and Wet part of troposphere can be estimated.

Dry part of Troposphere:

$$SDD = 0.002277 * P --- Eq(8)$$

Wet Part of Troposphere:

$$SWD = 0.002277 * WV\left(\frac{1255}{T} + 0.05\right) --- Eq(9)$$

Total Troposphere Delay

$$d_{trop} = SDD + SWD --- Eq(10)$$

STD -Saastamoinen Total Delay in meters.
SDD - Saastamoinen Dry Delay in meters.
SWD - Saastamoinen Wet Delay in meters.
T -Temperature in Kelvin.
WV -Water Vapor in millibars.
P -Pressure in millibars.

6 RESULTS

The Results are based on the observation data and meteorological data collected for the IISC site, Bangalore, Karnataka, India. IISC is one of the IGS stations and it is located at Lat/Long: $13.05^0/77.57^0$. The data at 6:00 hr GPS time of a typical day i.e August 1st 2012 is collected and estimated the Ionosphere delay and Troposphere delay for that Epoch.

The pr1 and pr2 codes available from GPS observation file and it is shown below

SATELLITES	PR1 in meters	PR2 in meters
G01	22975713	22975724
G07	21390262	21390268
G08	23206456	23206465
G10	24368734	24368747
G11	22070010	22070016
G13	20392589	20392594
G17	22801574	22801580
G19	22945966	22945972
G23	22196014	22196020
G28	22792513	22792519

Tabular form (2) Satellites and their Pseudo Ranges for 6:00 hour Epoch at IISC

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According to the values we can say that the satellite G10 is at a higher distance (24,368 km) from the surface of the earth and satellite G13 is at a shorter distance (20,392 km) from the surface of the earth.

6.1 IONOSPHERE DELAY

Using the Table (2) values we can calculate the TEC present in ionosphere layer Encounter with each Satellite can be estimated.

SATELLITES	TEC in TECU	IDL1 in meters	IDL2 in meters
G01	111.95	18.18	29.94
G07	53.69	8.72	14.36
G08	87.3	14.17	23.34
G10	117.47	19.07	31.41
G11	60.93	9.89	16.29
G13	49.41	8.02	13.21
G17	54.45	8.84	14.56
G19	57.02	9.26	15.25
G23	54.07	8.78	14.46
G28	57.59	9.35	15.4

Tabular form (3) Satellites and their Pseudo Ranges for 6:00 hour Epoch at IISC

The TEC encounter with each satellite is plotted and shown in Fig.2 below.

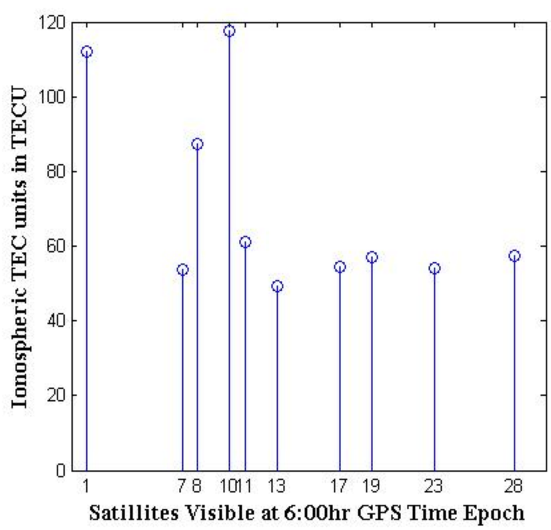

Fig (2) Satellites vs TEC in ionosphere for 6:00 hour Epoch at IISC

As per the plot we can say that G10 satellite encounters high TEC (117.47 TECU) and G13 satellite encounters less TEC (49.41 TECU).

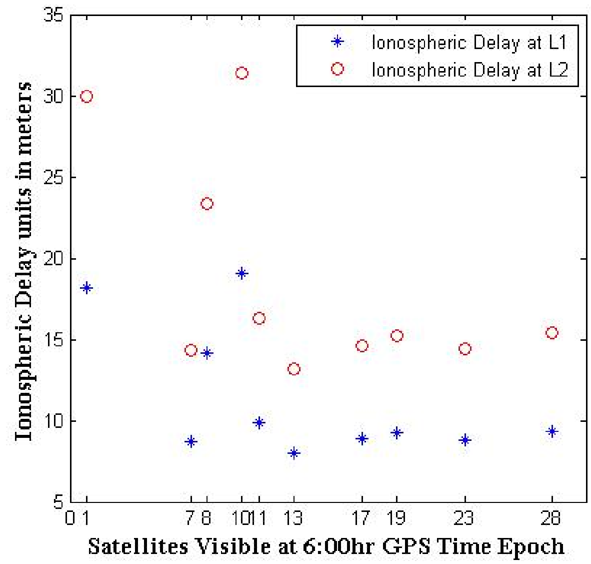

Fig (3) Satellites vs Ionosphere Delay at 6:00 hour Epoch of IISC

Ionospheric Delay at L1 frequency

As per the plot we can say that the GPS signal transmitted at L1 frequency by G10 satellite suffers from maximum ionospheric delay (19.07 meters) and the GPS signal transmitted at L1 frequency by G13 satellite suffers from minimum ionospheric delay (8.02 meters).

Ionospheric Delay at L2 frequency

As per the plot we can say that the GPS signal transmitted at L2 frequency by G10 satellite suffers from maximum ionospheric delay (31.41 meters) and the GPS signal transmitted at L2 frequency by G13 satellite suffers from minimum ionospheric delay (13.21 meters).

From the above results we can say that when the GPS signal is transmitted on both higher frequency (L2) signal and lower frequency (L1) signal, Higher frequency signal (L2) encounters more noise as compared to lower frequency signal (L1).

6.2 TROPOSPHERE DELAY

The Tropospheric delay is estimated using saastamoinen model and shown in tabular form (4). It is not possible to estimate the exact Tropospheric delay as compared to Ionospheric delay.

MET parameters	Values	Units
P	908.4	millibars
T	299.80	kelvin
RH	61.60	%
WV	21.5213	millibars
SDD	2.068427	meters
SWD	0.207587	meters
STD	2.276013	meters

Tabular form (4) MET data of Troposphere Region for 6:00 hour Epoch at IISC

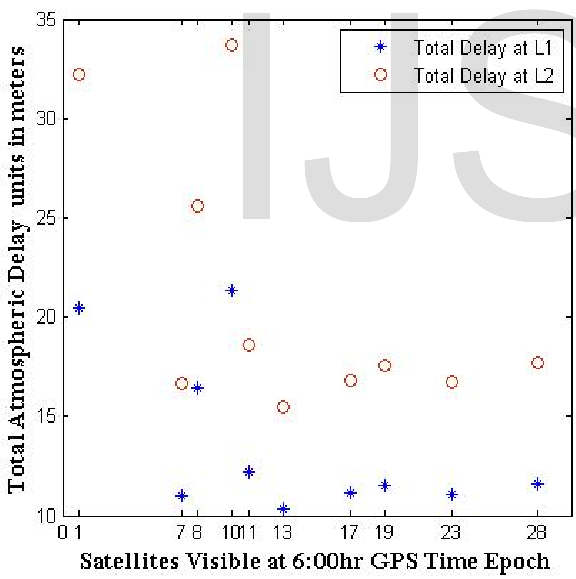

Fig (4) Satellites vs Total Atmospheric Delay at 6:00 hour Epoch of IISC

As from the results we can say that Maximum Atmospheric delay is caused by ionosphere region and Minimum Atmospheric delay is caused by Troposphere region.

SATELLITES	TOTAL DELAY AT L1 in meters	TOTAL DELAY AT L2 in meters
G01	20.45	32.21
G07	10.99	16.63
G08	16.45	25.62
G10	21.35	33.69
G11	12.17	18.57
G13	10.3	15.49
G17	11.12	16.84
G19	11.53	17.52
G23	11.06	16.74
G28	11.63	17.68

Tabular form (5) Total Atmospheric for 6:00 hour Epoch at IISC

SATELLITES	PSEUDO RANGE in meters	TRUE RANGE in meters
G01	22975713	22975692
G07	21390262	21390251
G08	23206456	23206439
G10	24368734	24368713
G11	22070010	22069998
G13	20392589	20392579
G17	22801574	22801563
G19	22945966	22945954
G23	22196014	22196003
G28	22792513	22792501

Tabular form (6) Comparison of Pseudo Range and True Range for 6:00 hour Epoch at IISC

After Eliminating the Ionosphere and Troposphere delays from the Pseudo Range we get the True Range values shown in tabular form (6).

7 CONCLUSIONS

In this paper, by collecting the observation and meteorological data for IISC site, Bangalore, Karnataka, India which is located at Lat/Long: $13.05^0/77.57^0$. To Estimate and Model the Atmospheric Delay for 6:00 hour Epoch of 1^{st} August 2012. As per the results we can say that among the 10 satellites of 6:00 hr epoch the GPS signal transmitted from G10 satellite is more diluted as compared to the GPS signal transmitted from G13 satellite. This work can be extended further by eliminating the all remaining error sources from the ranging information, with which it is possible to obtain more accurate GPS positioning.

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