Use of varying shell heights derived from ionosonde data in calculating total electron content (TEC) using GPS- new method.

***S .C.Mushini*[1], *P.T. Jayachandran*[2], *R.B.Langley*[3], *J.W. MacDougall*[4]**

[1]Department of Physics, University of New Brunswick, Fredericton, NB, Canada, E3B 5A3 (m4s86@unb.ca / Tel: (506) 453-4634)

[2]Department of Physics, University of New Brunswick, Fredericton, NB, Canada, E3B 5A3 (jaya@unb.ca / Tel: (506) 447-3330)

[3]Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, NB, Canada, E3B 5A3 (lang@unb.ca / Tel: (506) 453-5142)

[4]Department of Electrical Engineering, University of Western Ontario, London, Ont., Canada, N6A 5B9 (jmacdoug@uwo.ca / Tel: (519) 661-2111 ext: 86934/ Fax: (519) 661-3488)

Abstract

The dispersive nature of the ionosphere makes it possible to measure its total electron content (TEC).The Global Positioning System, which uses dual-frequency radio signals, makes it an ideal system to measure TEC. It was observed from ionosonde data from the polar region that the height of an approximated thin shell of electrons is not fixed but rather changing with time. Here we introduce a new method in which we included the real height derived from the ionosonde to map the slant total electron content from GPS to obtain a more precise vertical total electron content of the Ionosphere contrary to some previous methods which used fixed shell heights.

1. Introduction

The Global positioning System's availability both spatially and temporarily and also its usage of dual-frequency signals (F1=1.575 GHz and F2 = 1.228 GHz) make it a very suitable system for ionospheric research. The phase advance and the group delay in the GPS signals produced by the ionosphere depend on its total electron content (TEC) and by using these advances and delays one can calculate the total electron content along the path the ray has traveled from the satellite to the receiver through the ionosphere. [1]

Some previous studies have assumed the ionosphere to be a thin layer around the earth at a height at which the electron density is the maximum. The point at which the ray path intersects this layer is called the ionospheric pierce point and the electron content derived from the advances and delays along that ray path is assumed to be at that point. This electron content is called the slant total electron content since the ray path makes an angle with the vertical. This slant TEC is then mapped to the vertical using a mapping function to obtain vertical total electron content (VTEC) [1, 2].However, for the Polar Regions the fixed shell height assumption may not be valid since the ionosphere is very dynamic because of the Solar Wind – Magnetosphere – Ionosphere interaction and presence of ionospheric structures such as polar patches [3].

The ionosonde is another device which is generally used to profile the ionosphere. It's basically a vertical sounder of the ionosphere which sweeps over a frequency range of 1-20 MHz and works on the principle of reflection [4]. Given the dispersive nature of the ionosphere,the height we obtain is called the virtual height. To obtain the real height from this virtual height, one has to use numerical methods and the commonly used method is the Polynomial Analysis (POLAN) [5]. From ionosonde profiles, we also obtain the peak frequency and peak heights which correspond to the plasma frequency and height of the maximum electron density at that epoch respectively. This peak height is observed to be not constant in time and these peak heights obtained from the ionosonde were used as shell heights in our analysis of the GPS data. We mapped slant TEC's obtained from GPS data to the vertical using a mapping function. We used sun-fixed solar geomagnetic coordinates in our calculations since ionosphere varies much slower in these coordinates [8].

2. Data Analysis

In this study we have used GPS and Canadian Advanced Digital Ionsonde (CADI) measurements from Resolute Bay (74° 41′ 51″ N, 94° 49′ 56″ W), which is in the polar cap. For the details of the CADI system please see [3]. Since the ionosonde gives profiles only up to the peak of the F layer, topside profile is modeled using a Chapman function [6, 7] and then we integrated the whole profile to get the TEC. For this analysis we have used data for three days of 2006. [11^{th} November, 12^{th} November, and 15^{th} November 2006]. Analysis performed on the GPS data is described below.

International GNSS (IGS), provides 30sec dual-frequency data files (observational, navigational and meteorological) of which we are mainly interested in observational files. These observational files contain information about range measured in meters on P1, P2 (P-code pseudo ranges on F1, F2 respectively) and C1 (C/A code pseudo range on F1). They also have phase information (L1 and L2) measured in cycles on F1 and F2 frequencies. We calculated the slant absolute total electron content (SATEC) from pseudo ranges and slant relative total electron content (SRTEC) from the carrier phases using equation (1) and equation (2) [2].

$$\mathrm{SATEC} = \left(\left[\left(\frac{\mathrm{P}_2}{\mathrm{c}} \right) - \left(\frac{\mathrm{P}_1}{\mathrm{c}} \right) \right] * 2.852 * 10^{+9} \right) \quad (1)$$

$$SRTEC = \left(L_2 - \left(\frac{60}{77} \right) L_1 \right) * (-2.3247) \quad (2)$$

The relative slant total electron content is relative in the sense that there is an ambiguity in the phase which does not give an absolute value but it is very precise. The absolute total electron content from the pseudorange is absolute but noisy. To obtain a better result we combined them using a method called phase leveling [1, 2]. Since GPS hardware have their inherent delays (satellite bias and receiver bias), they should also be taken into consideration [1, 2].

We obtained these bias values from the University of Bern website (http://www.aiub-download.unibe.ch/CODE/) and combined them with our slant absolute total electron content before we did phase leveling [2]. This phase leveled slant total electron content is called the slant total electron content. While analyzing the data, cycle slips, where the phase is lost for a certain period of time, were checked for and corrected before phase leveling was done. After obtaining the slant total electron content, we used the mapping function, M(E) (equation (3)), to obtain the vertical slant total electron content at the ionospheric pierce point at the shell heights obtained from ionosonde. We then mapped the vertical TEC from the pierce point to the receiver. Later we averaged the vertical total electron content from each satellite to obtain the averaged vertical total electron content .The elevation angles (E) between the receiver and satellites were obtained from GPS Tool kit designed by the University of Texas, Austin [9].

$$M(E) = \frac{1}{\cos\left(\arcsin\left[\cos(E) \frac{R_e}{R_e + h} \right] \right)}$$

(3), R= radius of earth, h = shell height [1]

3. Results

Figure 1(a,b) shows the scatter plot of the differences between the vertical total electron content obtained using a fixed shell height at 350km and varying shell heights obtained from the ionosonde and peak frequency and shell height respectively. The maximum difference between the vertical electron content obtained using a fixed shell height and by using varying shell height is around 0.3TECU. It is to be noted that the difference increases proportionally with the increase in total electron content which is proportional to the peak frequency.

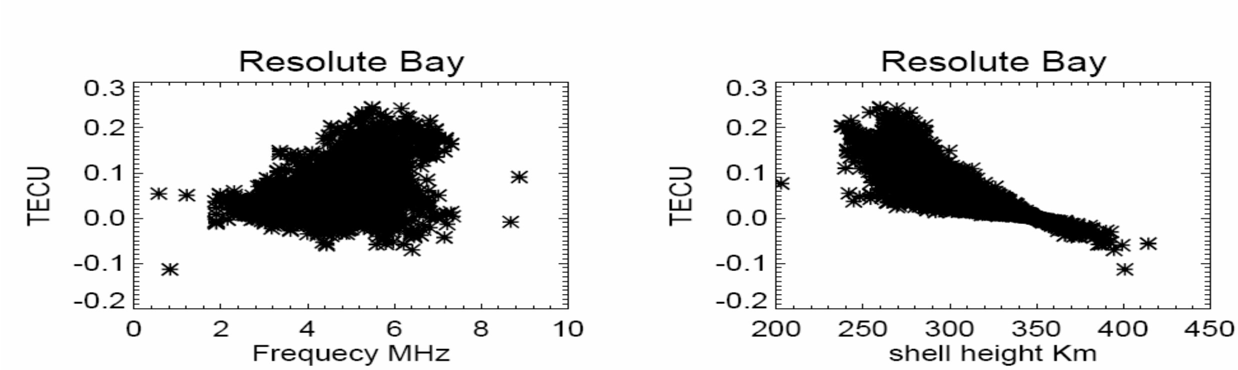
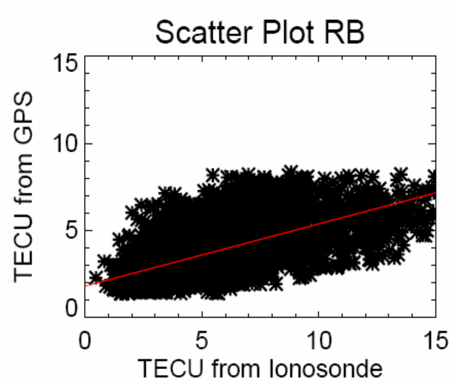


Figure 1(a,b). The difference between the total electron contents derived from GPS using a fixed shell height analysis with shell height at 350km and using varying shell heights analysis is plotted against peak frequency and shell height respectively at Resolute Bay(74° 41' 51" N, 94° 49' 56" W) on 11th, 12th, 15th November 2006. The varying shell heights were obtained from ionosonde. The difference is observed to increase where there is an increase in the electron content in the ionosphere.(1TECU = 10^{16} electrons/m^2)



Fig*ure 2. This shows the correlation of total electron content derived from GPS using varying shell height analysis and total electron content obtained from Ionosonde at Resolute Bay(RB)(74° 41' 51" N, 94° 49' 56" W) on 11th, 12th, 15th November 2006.. The correlation coefficient is 0.607. The shift/bias of ~1.7 TECU observed in the plot is attributed to receiver bias estimation and mapping functions used. .(1TECU = 10^{16} electrons/m^2)*

Figure 2 shows the scatter plot between the ionosonde derived TEC and the GPS VTEC (using ionosonde derived shell heights) for the three days. Agreement between the two TEC is evident in the figure (0.61 correlation coefficient). We have also correlated (figure not shown) ionosonde TEC and GPS VTEC using fixed shell height and correlation coefficient was lower (0.59). The correlation improved slightly when the ionosonde derived shell heights were used.

4. Discussion

The ionosphere is a very dynamic system which changes both spatially and temporarily. Most past studies assumed that the electron densities in the ionosphere have a constant structure with time and this led to the assumption that the peak layer or the layer at which the electron density is constant at a single height and it is around 350km. For precise ionospheric studies, this approximation cannot be made. Some previous studies took varying shell heights in to consideration but these shell heights were obtained from ionosphere models [10]. We saw in our ionosonde data analysis that shell height varies from 250km to 400km. This we think is a significant change in the ionosphere which should be taken into account. It is seen in figure (1(a)) that the difference between the electron contents derived from using a varying shell heights derived from ionosonde data and a fixed shell height at 350km, increases as the electron content in the ionosphere increases with time. This shows that if there is an increase in electron content due to solar activities, the fixed shell method is not accurate enough. From the scatter plot (figure 2) between the total electron content derived from GPS and total electron content from Ionosonde for all 3 days, we observed that the electron content derived from ionosonde is more than GPS derived electron content by 1.7 TECU.

The shift or bias in the scatter plot was attributed to plasmasphere electron content in ionospheric studies at midlatitudes [11]. Since our station is in the polar region, the plasmasphere's contribution is negligible. As less than 5% is the error that can be attributed to ionosonde derived TEC [6], we think that most of this shift or bias observed in our results is mainly due to two reasons. The first one we think is the receiver bias. It has to be noted that receiver biases which were used were monthly averages. Recent studies also show that for higher latitudes above 60N, there is no proven method which would give us an accurate receiver bias [12]. The second reason we think that may affect the results is the mapping function. The general mapping function we used is designed best for mid and low latitudes where the highest elevation angle of the GPS satellites can be 90 degrees [1]. For higher latitudes this is not true since the satellite elevation is never 90degrees This shows that in depth studies are required to design a mapping function for higher polar latitudes and as well as for receiver bias calculations for GPS receivers at high latitudes given the activity in the higher latitude ionosphere. Precise ionospheric studies should also include varying shell heights since the ionosphere is not constant in time.

5. Acknowledgements

We would like to thank Natural Sciences and Engineering Research Council (NSERC), Canada and Canadian Space Agency (CSA) for providing us funding to make this work possible.

6. References

1. Komjathy.A, "Global Ionospheric Total Electron Content Mapping Using the Global Positioning System", *PhD dissertation, Department of Geodesy and Geomatics Engineering Technical Report No.188, University of New Brunswick, Fredericton,New Brunswick, Canada* , 1997.

2. I.Horvath, and S.Crozier, "Software developed for obtaining GPS-derived total electron content values" *Radio Science 42,* RS2002, doi: 10.1029/2006RS003452

3. J. W. MacDougall, and P. T. Jayachandran, "Polar Patches: Auroral precipitation effects", Journal *of Geophysical Research.*, 2007, 112, A05312, doi: 10.1029/2006JA011930.

4. K.Davies, "Ionospheric Radio", *IEE Electromagnetic waves series*, 1990, 31, ISBN 086341186X

5. Titheridge.J.E , " Ionogram Analysis : Least squares fitting of a chapman layer peak", *Radio Science*,1985, 20, No: 2, Pp: 247-256.

6. X.Huang , and B.W. Reinisch, "Vertical electron content from ionograms in real time" *Radio Science,*2001, *36,* Number 2, pp: 335-342.

7. Chapman.S, "The absorption and dissociative or ionizing effect on monochromatic radiation in an atmosphere on a rotating earth", Proceedings of the Physical Society, 1931, Vol. 43, No. 1, pp. 26-45.

8. S.Bregstrand, and R.Haas, "Comparision of Ionospheric Activity Derived from GPS and Different VLBI Networks"*, IVS General Meeting Proceedings*, 2004.

9. T.Gaussiran, D.Muncton, B.Harris, and B.Tulman, "An open source Toolkit for GPS Processing, Total Electron Content Effects, Measurements and Modeling", *International Beacon Satellite Symposium*, Italy, 2004

10. A.Komjathy and R.B.Langley, "The Effect of Shell Height on High Precision Ionospheric Modelling Using GPS", *Journal of Geophysical Research*, 1996, 101, B2, pp: 3227-3246

11. L-A.McKinnell, B.Opperman and P. J. Cilliers, "GPS TEC and ionosonde TEC over Grahamstown, South Africa: First Comparisons", 2007, *Advances in Space Research,* 39, pp: 816-820

12. W.Rideout, and A.Coster, "Automated GPS processing for global total electron content data", *GPS Solutions*, 2006, DOI: 10.1007/s10291-006-0029-5