Ionospheric non-homogeneity effects on TEC calculation

Ivan. J. Kantor, Eurico.R de Paula, Patrícia M. Siqueira (INPE)

Abstract

The Ionosphere over Brazil is normally non-homogeneous, due to phenomena like the Equatorial Ionospheric Anomaly (EIA). Measurements of VTEC for one station can produce a TEC map that will not correspond to the true TEC if non-homogeneity is present. The effect of density gradients on TEC measurements is analyzed, using ionospheric models and real data.

INTRODUCTION

The Total Electron Content (TEC) is the amount of free electrons along the path of the electromagnetic wave between each satellite and the receiver, given by

$$TEC = \int_{receiver}^{satellite} N \cdot ds$$

where *N* is the electron density.

It is an important geophysical parameter, which has also applications for correcting navigation measurements for single frequency receivers.

The TEC has been measured for decades using the Faraday Rotation effect on a linear polarized propagating plane wave (Klobuchar, 1985 and 1996). Special transmitters in geostationary and non-geostationary satellites were used for this purpose. But today TEC measurements are made mostly using GPS data, , which can provide at least 4 and up to maybe 9 TEC values within 1000 km from the receiving station simultaneously every 30 seconds (usual period).

GLOBAL POSITIONING SYSTEM (GPS)

The main purpose of the GPS is to determine the position and velocity of a fixed or mobile object, placed over or near the earth surface, using the signals of the 24 satellites on earth orbit. Details in Monico (2008), Hoffmann-Wellenhof et al. (1994), Leick (1995) and Seeber (1993).

This satellite constellation called Global Positioning System (GPS) was developed for other than geophysical motives, but can and should be used by the geophysics community.

GPS is a complex and expensive constellations of 24 satellites distributed in 6 orbital planes, 4 satellites per plane, at 20,200 km altitude, with an orbit inclination of 55 degrees and an approximately 12 hour period

There are today a great number of GPS receiving stations able to provide TEC measurements. The International GPS Service has 357 active stations as of 19 Apr 2011, being 3 in Brazil. Besides those, in Brazil there is the local GPS stations network RBMC (Rede Brasileira de Monitoriamento Contínuo) with 90 stations.

MOTIVATION

It is of geophysical interest the vertical TEC, VTEC, which associates its value to a geographical position (latitude and longitude) at a given time.

With the GPS the measured TEC is the slant, which crosses several geographical positions. If the Ionosphere is homogeneous, to convert slant to vertical TEC is a geometrical problem. But in general the Ionosphere is not homogeneous, especially in the equatorial region with the Equatorial Ionospheric Anomaly (EIA).

How these non-homogeneities affect the measured TEC ? How could they be corrected? If they can.

This work analyses how the ionospheric non-homogeneity affects the measured vertical TEC.

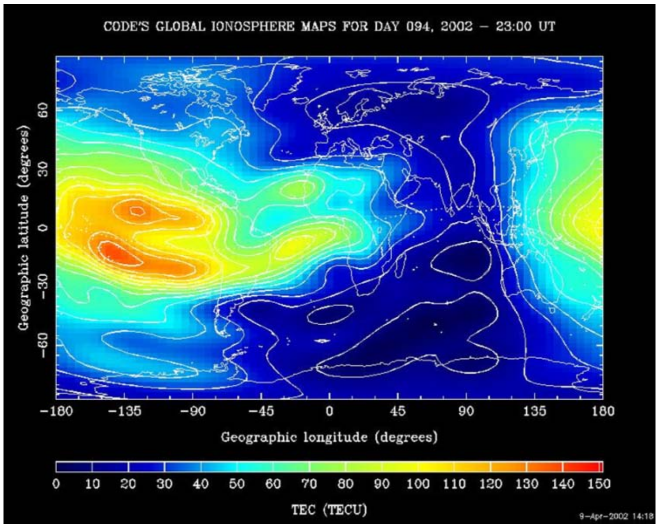

Figura 1 - *Example of a TEC contour map of CODE's Global Ionospheric Map, in geographic latitude and longitude. Day 094, 20:02 - 23:00 UT*

DATA AND MODELS UTILIZED

For this study several ionospheric models and data were utilized:

- The simples model is the "rectangular model" $N(h,r)=\begin{cases} N_0 & h_1<h<h_2 \\ 0 & h<h_1 \text{ , } h>h_2 \end{cases}$

Actual TEC is given by

$$I(r)=\int N(h,r)dh = N_0(h_2-h_1)=N_0\tau$$

where τ is the slab thickness.

- Other model to be used is the Chapman layer $N(h)=N_0\cdot\exp(1-z-\exp(-z))$

where $z=(h-h_0)/H$ and *H* is the scale height.

- International Reference Ionosphere – IRI-2007

- NeQuick model will also be used.

- INPE's Digisonde DGS 256 data was provided by M.G.S.Aquino.

- Equatorial anomaly cross sections calculated by SUPIM model at 20 LT during equinox of solar maximum (F10.7 = 180), provided by Jonas R.de Souza.

Depending on the possible results, some calculations were made for flat earth and some for spherical.

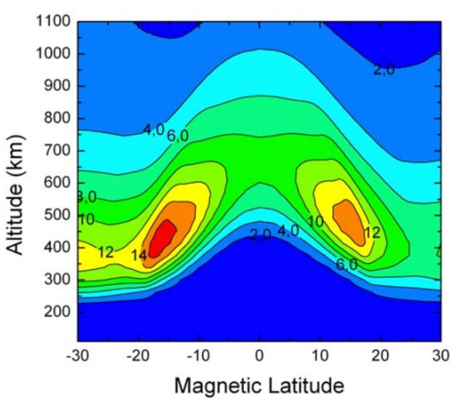

Figura 2 *- Equatorial anomaly cross sections calculated by SUPIM model at 20 LT during equinox of solar maximum (F10.7 = 180).*

AMPLITUDE VARIATION

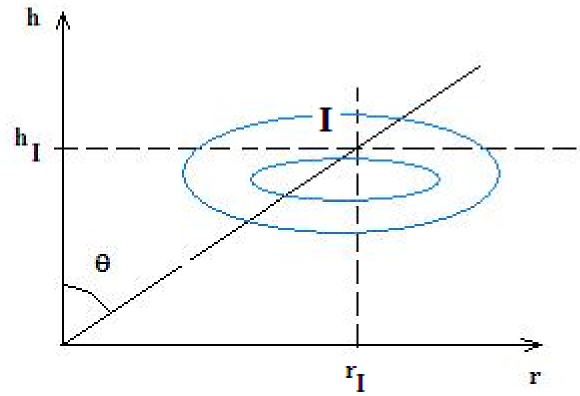

Figura 3 – *Equatorial anomaly cross section model*

Let's begin with a flat earth.

Given $N(h,r)$ at a given epoch *t* :

Actual TEC at distance r_I

$$I(r_I)=\int_0^\infty N(h,r_I)\,dh$$

Measured slant TEC

$$I_S(\theta)=\int_0^\infty N(h,r)\,ds=\frac{1}{\cos\theta}\int_0^\infty N(h,h\cdot tg\theta)\,dh$$

where $r=h\cdot tg\theta$, $s=dh/cos\theta$

Vertical measured TEC

$$I'(\theta)=\cos\theta\cdot I_S(\theta)=\int_0^\infty N(h,h\cdot tg\theta)\,dh$$

associated with $r_I=h_I\cdot tg\theta$.

Problem: How to estimate the actual TEC knowing measured TEC..

Observe that if the density *N* does not change with *r* , $I(r_I)=I'(r_I)$.

Let's introduce a horizontal gradient with no height variation of the form:

$$N(h,r)=p(r)\cdot N_0(h)$$ and

$$p(r)=1+a_1r_I+a_2r_I^2+\cdots$$

Actual TEC

$$I(r_I)=p(r_I)\int_0^\infty N_0(h)\,dh$$

Measured VTEC

$$I'(r_I) = \int_0^\infty N(h, h \cdot tg\theta)\, dh$$

$$= \cdot\left[1 + a_1 r_I m_1 + a_2 r_I^2 m_2 + \cdots\right] \cdot \int_0^\infty N_0(h)\, dh$$

where

$$m_i = \frac{1}{h_I^i} \cdot \frac{\int_0^\infty h^i N_0(h)\, dh}{\int_0^\infty N_0(h)\, dh}$$

The coefficients m_i are adimensionals depending on the profile form.

From the measured VTEC a polynomial fit of the radial variation can be made.

The coefficients m_i depend mostly on the profile form

For the rectangular model

$$m_n = \frac{1}{h_I^n} \cdot \frac{\int_0^\infty h^n N_0(h)\, dh}{\int_0^\infty N_0(h)\, dh} =$$

$$= \frac{1}{(n+1)\, h_I^n} \cdot \frac{h_2^{n+1} - h_1^{n+1}}{h_2 - h_1}$$

$$m_1 = \frac{1}{2h_I} \cdot \frac{h_2^2 - h_1^2}{h_2 - h_1} = \frac{h_2 + h_1}{2h_I} \cong 1$$

Linear amplitude variations does not present change on the measured VTEC

HEIGHT VARIATION

If electron density changes only with height

$$N(h, r) = N_0(h + b \cdot r)$$

Actual TEC at distance r_I

$$I(r_I) = \int_0^\infty N_0(h + b \cdot r)\, dh = \int_0^\infty N_0(h)\, dh = I_0$$

Vertical measured TEC

$$I'(\theta) = \cos\theta \cdot I_S(\theta) = \int_0^\infty N(h, h \cdot tg\theta)\, dh$$

associated with $r_I = h_I \cdot tg\theta$

$$I'(\theta) = \int_0^\infty N_0(h + b \cdot r \cdot tg\theta)\, dh = \frac{I_0}{1 - b \cdot tg\theta}$$

EFFECT OF EARTH CURVATURE

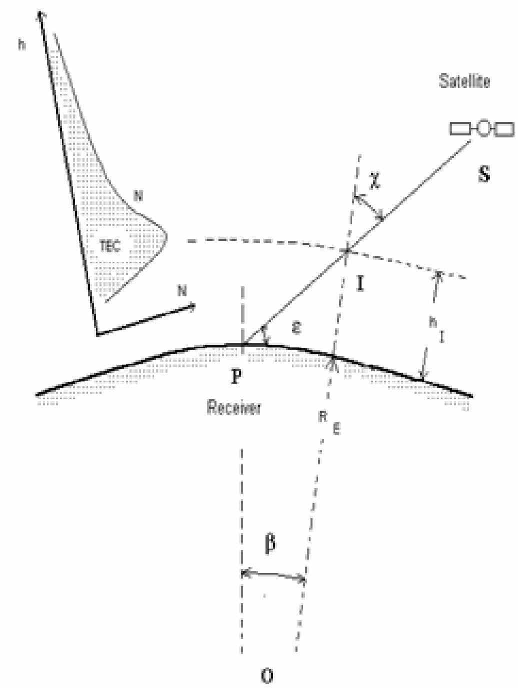

***Figura 4 –** Satellite-Earth diagram*

The following equations are used to calculate parameters accounting for the earth curvature:

$$\frac{\sin\chi}{R_E} = \frac{\sin(E + 90°)}{R_E + h_I} = \frac{\sin\beta}{s}$$

$$VTEC = \cos\chi \cdot sTEC$$

To calculate s

$$\sin\chi = \frac{R_E}{R_E + h_I} \sin(E + 90°)$$

$$\beta = 90 - E - \chi$$

$$s = \frac{R_E \_ h_I}{\sin(E + 90)} \sin\beta$$

SIMULATION

Simulations are done for the cases of greater ionospheric non-homogeneity: with Equatorial Anomaly and the Day and Night transition.

Observe that the non-homogeneity is azimuthal relative to the receiver position.

Actually testing the relation between actual and measured VTEC with real data is very difficult, due to the difficulty of obtaining actual data close to the receiving station.

CONCLUSION

Some theoretical results were obtained for amplitude variation with no height variation and only height variation.

But much more is still to be done.

To use real GPS data from a single station accumulated data from an azimuthal sector.

Analyze variations from shape parameters of the ionospheric profile.

Study the possible use of the results in multi-stations TEC maps.

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