Regional Computation of TEC using a Neural Network Model

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Introduction

Ionospheric refraction is one of the most damaging effects on GPS signal. This effect is proportional to the total electron content (TEC), which is the number of free electrons contained in the ionospheric layer. Electrons of atmosphere are generated due to several factors, including solar activity. Once the TEC is known, it is possible to determine the delay caused by the ionosphere on GPS signal. Due to the dispersive characteristic of the ionosphere, the delay is a function of the frequency. It is possible to know the value of TEC using a dual frequency GPS receiver. Using the observations at both frequencies it is possible to compute the TEC value for the local where the station is.

One alternative for single frequency receiver users is to use a regional model of TEC, generated by using data from a tracking network of dual frequency receivers. There are several ways to create such model. A network of receivers can generate a spatially distributed grid of TEC values. Using this grid it can be created a model from which is possible to estimate a TEC value to any position inside or near the region covered by the tracking network. Once the local TEC value is estimated, it is possible to correct the single frequency receiver observations. In this paper we present a new technique to regional TEC modeling, using a Neural Network approach. This new technique has the capability to predict TEC values derived from a GPS tracking network. Preliminary tests using the new technique indicate an average accuracy in the TEC values estimation of 98 %. In other words we can correct the ionospheric delay by the same amount, due to its direct relationship with TEC. These preliminary tests and respective results will be shown later in the paper.

TEC computation to a dual frequency receiver

This section deals with the first step of our technique, that is the computation of the Vertical TEC (VTEC), using dual frequency observations. This computation allows the determination of VTEC values for each station of the tracking network. The model for VTEC computation presented here is a simple model, because our final objective is not to get a great precision in the VTEC determination for the tracking station itself, but a good estimation using our regional model for void areas, which is the main subject of this work. These same values can be computed using different techniques, probably providing a better quality input data to the regional model. However it will be shown that the final results obtained using our approach are satisfactory.

For simplification we assumed the TEC as a constant value during the period used for the computation. The choice of the size of such period is arbitrary, but it needs to be large enough to provide a good number of degrees of freedom in the adjustment and small enough to satisfy the assumption that TEC is constant over that period. In this work, we used periods of one hour for each determination of TEC.

TEC is defined as being the number of free electrons contained in a column with one meter squared of transversal section, along the path of the signal through the ionospheric layer. It is a number associated to an inclined trajectory with respect to the local zenith, as a function of the elevation angle of the satellite. In addition to that, the signal goes through the ionosphere at coordinates different from those of the station, at the ionospheric piercing point. To correct for the inclination and the position of the piercing point we can use mapping functions. The mapping function used in this work is a simple bilinear model. Equation 1 represents the final expression for TEC computation used in this work:

$$\frac{1}{\sin(el)} \cdot \left(a_0 + a_1 \cdot ?f + a_2 \cdot ??\right) + 9.52 \cdot C_r^s = 9.52 \cdot \left(?_2 \cdot f_{r2}^s(t) - ?_1 \cdot f_{r1}^s(t)\right), \qquad (1)$$

where el is the elevation angle of the satellite at the observing station, in radians, $?f$ is the latitude difference between the observation point and the ionospheric piercing point, in radians $??$ is the longitude difference between the observation point and the ionospheric piercing point, in radians, a_0, a_1 and a_2 are the coefficients of the bilinear model to be adjusted, in TECU, C_r^s is the combination of the ambiguity terms of the two frequencies, in meters, $?_1$ and $?_2$ are the carrier phase wavelengths, in meters, and $f_{r1}^s(t)$ and $f_{r2}^s(t)$ are the carrier phase measurements for a receiver r and a satellite s, in cycles.

The linear system formed by the several observations according to the equation (1) can be solved using the Parametric Least Squares Method. Performing this computation for each station of the GPS tracking network we will have a VTEC value associated to a coordinate wherever we have a station of the network. These values will be the input parameters of our Neural Network Model, which will perform the estimation of VTEC for any other point in or near the region covered by the network. The Neural Network Model will be discussed in the following section.

The Neural Network Model

The presented model was created to estimate the VTEC for a certain position. The input parameters of the neural network model are Latitude and Longitude, while the output parameter is the VTEC. In this way, once the network is trained, it is possible to get a VTEC value for any location. The training parameters are the known coordinates and VTEC values of each station of the GPS network at a given time. Once the model is adjusted we can estimate a VTEC to any position inside or near the region covered by the GPS network to the given time. A Multi Layer Perceptron network with two hidden layers (each one with five neurons) was used. The activation function of all layers (except the input one) is the hyperbolic tangent sigmoid function. The techniques to apply the model with the GPS tracking network data are discussed in the following section.

Analysis Strategy

The data used in this work was obtained from the RBMC (Brazilian Continuous Monitoring Network), which is a GPS tracking network in Brazil. The advantage of using that network is due to the continental dimensions of Brazil, what can be considered one additional factor to test the capability of the model to estimate the TEC to long distances. A total of 11 stations were used in this work.

For each determination the test station data was not used during the training process of the neural network. After the training process the model was used to estimate the VTEC value for the test station position. This value is then compared with the known VTEC value obtained with the techniques expalined in previous sections. The difference between them shows the error of the prediction of the Neural Network Model. Performing this procedure to each of the 11 stations we could access the eficiency of the model everywhere. Using this technique we could analise the performance of the model for predictions inside and at the edges of the area covered by the network.

We performed these tests for two different periods of five days: One with low solar activity and the other with high solar activity. The low solar activity period covered days form February 1st 2004 to February 5th 2004. The high solar activity period covered days from October 26th 2003 to October 30th 2003. For each day tests were performed to compute VTEC at 12, 14 and 16 hours (local time), corresponding to three predictions per day per station, resulting in a total of 318 predictions. The period used for the TEC computation was 1 hour. Prediction results are shown in the following section.

Results

Due to the direct relationship between TEC and ionospheric delay, we can correct the ionospheric delay with a similar accuracy of the estimation of TEC. The results of VTEC estimations can be regarded as an estimated accuracy for correcting the ionospheric delay to single frequency receivers.

In this investigation 318 estimations were made with our new model, involving different stations, days and time of the day. The average absolute error of all estimations is equal to 0.4 TECU with standard deviation of 0.6 TECU (1 sigma). The average relative error was 2 %, with standard deviation of 3.2 % (1 sigma). Figure 1 shows the average results of all estimations.

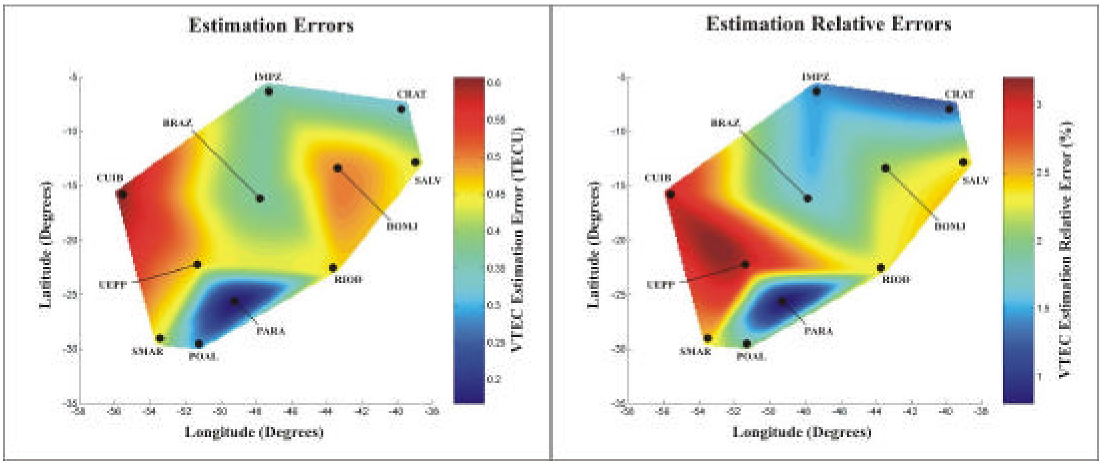

Figure 1 - Absolute and relative average errors for all stations.

Conclusions and Future Research

The model performed estimations with an average error of 0.4 TECU with standard deviation of 0.6 TECU (1 sigma). The average relative error was 2 %, with standard deviation of 3.2 % (1 sigma). This means that according to these preliminary results the new model allows to correct approximately 98 % of the ionospheric refraction to a single frequency receiver inside or outside the region. It can be concluded that the new model is adequate to predict VTEC values. The value of the standard deviations allow us to conclude that there was not great differences when comparing different stations, days, times or even solar activity levels.

Future research is required to a complete validation of the model, assessing the efficiency of the new technique to different conditions of geomagnectic and solar activity. Comparison of the estimations of this new model with current models is another way to validate of technique.

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