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. 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. Using the observations of two frequencies of a GPS receiver it is possible to compute the TEC value for the local where the receiver is. Single frequency receiver users can use a regional model of TEC, generated by using data from a tracking network of dual frequency receivers. 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 modelling, 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 accuracy in the TEC values estimation up to 98 %. In other words we can correct the ionospheric delay by the same amount, due to its direct relationship with TEC.

TEC computation using a dual frequency receiver

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:

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

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 are the input parameters of our Neural Network Model, which perform the estimation of VTEC for any other point in or near the region covered by the network.

The Neural Network Model

The presented neural network 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 neural 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. Figure 1 shows a scheme of the neural network model used.

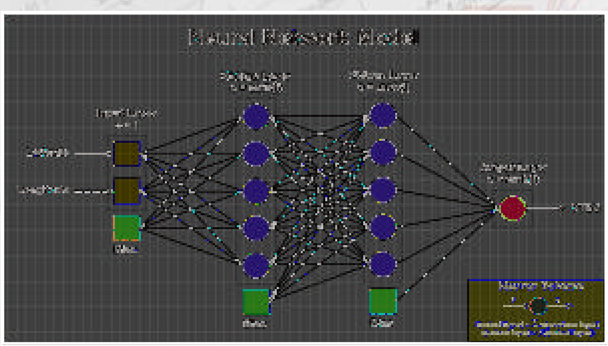

Figure 1. The Neural Network Model used.

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 (Figure 2). 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. All stations were used as a test station. For each determination the test station data was not used during the training process of the neural network. Using this technique we could analyse the performance of the model for predictions inside and at the edges of the area covered by the network. The days used in the analyses were chosen in function of the level of solar activity (high and low), as shown in figure 3.

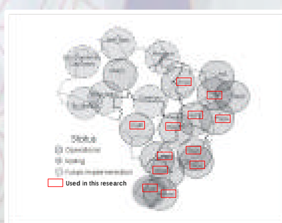

Figure 2. The GPS network.

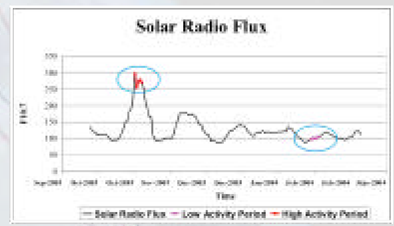

Figure 3. Days used in the analyses.

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 for best estimations is equal to 0.4 TECU. The average relative error for best estimations was 2 %. The average absolute error of all estimations is equal to 3.7 TECU with standard deviation of 2.7 TECU (1 sigma). The average relative error was 14.9 %, with standard deviation of 10.9 % (1 sigma). Figure 4 shows the average results of best estimations.

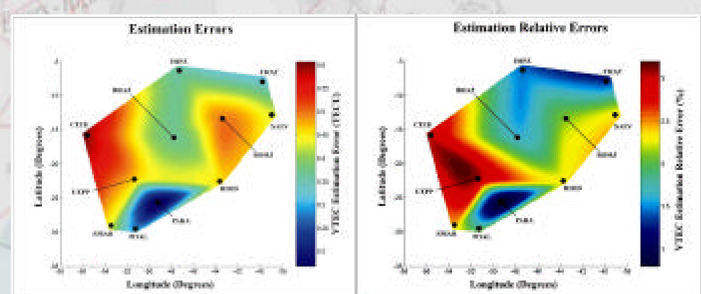

Figure 4. Results of best estimations.

Conclusions and Future Research

It can be concluded that, according to this preliminary results, the new model is adequate to predict VTEC values. The estimations were good either to stations inside the region of network or outside that. The performance of the model was satisfactory to the 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 geomagnetic 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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