Autocovariance Ionospheric Prediction Model for GAGAN Applications

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Abstract: ***Airports Authority of India (AAI) and Indian Space Research Organization (ISRO) are being jointly developing a satellite based augmentation system which is popularly known as GPS Aided Geo Augmented Navigation System (GAGAN) to cater civil aviation requirements in India. Forecasting of the ionospheric behaviour in advance can be used to set up early warnings of ionospheric threats for GAGAN system. In this paper, an ionospheric forecasting model is implemented on the basis of autocovariance method. The dual frequency GPS receiver's data of Hyderabad (Geographic 17.410N,78.550 E) station located at the National Geophysical Research Institute (NGRI),Government of India is considered for the analysis. Time series of vertical Total Electron Content (TEC) for all visible satellites are calculated for quiet days and disturbed days. In this method, the first prediction point outside the data time interval in the future and in the past is computed and added at the beginning or at the end of data, respectively. Using this first prediction point, the next prediction point is computed consequently. Forecasting of ionospheric delay variations would be immensely useful for the protection of valuable communication satellites from space weather conditions.***

Index Terms: ***autocovariance, forecasting, gps, gagan, and tec.***

I. INTRODUCTION

Global Positioning System (GPS) is widely used for navigation, positioning and time transfer [Ahmed El-Rabbany, 2001].When GPS signals propagate through the ionosphere, the carrier experiences a phase advance and the code experiences a group delay because of total number of free electrons along the path of signals obtained from the satellite to GPS receivers. TEC is an important descriptive quantity for the ionosphere of the Earth.TEC value equal to 1016 electrons / $m^2$is called one TEC Unit (TECU) [Ahmed El-Rabbany,2001].

In aircraft landing system, below 10feet accuracy is needed but in general GPS system will provide the accuracy up to 50 feet only, which is primarily due to the ionospheric errors.

Ionospheric time delay, as a function of TEC, is the major error source in GPS signals. The ionosphere exhibits an irregular behavior corresponding to large TEC fluctuations in equatorial regions. Ionospheric forecasting models will be of essential use in GAGAN because Indian region is located in between the equatorial region and beyond the equatorial ionization crest regions where the ionospheric delay variations are very predominant because of the presence of strong electric fields and the perfect horizontal nature of magnetic fields lines of the earth which results in the formation of vertical drifts leading to the so-called fountain effect.

The TEC forecasts were already done using the autocovariance method. In this method, the first prediction point outside the data time interval in the future and in the past is computed and that value is added at the beginning or at the end of data, respectively, so the next prediction point can be computed. This method does not require any information about solar–geophysical activity and it can be used for forecasting without any knowledge of the physical processes in a medium, such as the ionosphere (Kosek, W, 1997). The accuracy of the method varies within reasonable limits depending on the time range of the forecast for different conditions. The forecasted TEC values are compared with real data of the TEC obtained from GPS permanent observations.

II. AUTOCOVARIANCE METHOD

Autocovariance method is based upon the stationary stochastic process characteristics (Kosek, 1993). Time series of vertical TECv for all visible satellites are given as input to the autocovariance method and the first prediction point outside the data time interval in the future and in the past will be computed and added at the beginning or at the end of data, respectively.

Let X =X1,X2,…..Xn be an equidistant stationary stochastic process of N equally spaced observations and be the prediction at a time of N +1(I. Stanis awska and Z. Zbyszyn´ski 2003).

In this autocovariance method, the estimated first predicted point will be satisfy the below condition.

$$P=\sum_{k=0}^{N-1}(x' - x_k) = \text{minmum} \quad (1)$$

Where

$$x_k = \frac{h_k}{N-k}\sum_{t=1}^{N-k} X_t X_{t+k} \quad k = 0,1,\ldots.,N-1. \quad (2)$$

$$x'_k = \frac{h'_k}{N-k+1}\sum_{t=1}^{N-k} X_t X_{t+k} \quad k = 0,1,\ldots\ldots N, \quad (3)$$

The first prediction estimation X' added to the end ofthe data enables computation of the next prediction estimation X'. The lag windows with the lengths of n and $n+1$ are

Manuscript received on July 2012

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given by v_k and w_k.The solution of these equations is the first prediction estimation points.

$$\hat{X}_{n+1} = \frac{-\sum_{k=1}^{n-1} g_{kh_k}\left(a^{\hat{}}_{kx_{n-k+1}} + b_k^{\hat{}}\, y_{n-k+1}\right)}{\sum_{k=1}^{n-1} g_k^2 \left(x_{n-k+1}^2 + y_{n-k+1}^2\right)} \quad (4)$$

Where

$$a_k^{\hat{}} = c_{xx}^{'n}(k) + c_{yy}^{'n}(k)$$

$$b_k^{\hat{}} = c_{yx}^{'}(k) - c_{xy}^{'n}(k)$$

$$h_k = v_k - w_k \frac{n-k}{n-k+1}$$

$$g_k = -\frac{w_k}{n-k+1}$$

III. DETERMINATION OF TEC

Ionosphere is a dispersive medium its allows correction of range delay errors of first order. The time delay errors of ionosphere estimating using single frequency process, its can eliminate up to 50 to 60 % errors only. A dual frequency GPS receiver can diminish the ionospheric time delay through a linear combination of L1 (f1=1575.42 MHz) and L2 (f2 =1227.60 MHz) observables. The required data for the measurement of TEC obtained from observation data Scripps Orbits and Permanent Array Center (SOPAC) data in Receiver Independent Exchange (RINEX) data format from the SOPAC data archive networks (http://sopac.ucsd.edu/dataArchive). The data is available for every 30 seconds. While estimating TEC, the ionosphere was approximated as a single layer at a fixed height of 350 km above the Earth’s surface because this region has the highest variability of free electrons, causing the greatest effect on GPS received signal compared to other layers.

The TEC can be obtained by [Pratap Misra, 2001]

$$TEC = \frac{1}{40.3}\left(\frac{f1f2}{f1-f2}\right) * (p2 - p1) \quad (5)$$

WhereP1 and P2 are the pseudo ranges measured in L1 and L2, respectively corresponding to the high GPS frequency (f1=1575.42 MHz) and the low GPS frequency (f2 =1227.6 MHz), respectively. The simple geometric factor was used to convert slant TEC into vertical TEC values. The measured VTEC values from GPS data are given as input data to the autocovariance method.

$$VTEC = STEC * \sqrt{(1 - (\frac{R_e \cos_\theta}{h_s + R_e})2} \quad (6)$$

WhereR_e the radius of the Earth, θ is the elevation angle of the satellite, and $h_s$is the median height of the ionospheric layer, which is commonly assumed to be 350 km.

IV. RESULTS AND DISCUSSION

In this paper, the VTEC measurements for two Indian IGS stations, located at Hyderabad (Geographic 17.410 N, 78.550 E) and Bangalore (Geographic 13°1'14"N 77°33'58"E) are used to study the day to day prediction of TEC by using auto covariance method.In Fig1(a), the VTEC prediction for the period 3rd -8th April 2012, at Hyderabad station is shown. Fig 1(a) shows periodicity of diurnal behaviour of ionosphere. The maximum TEC (70 TECU) is observed on 6th April 2012. The prediction error of the TEC data is shown in Fig 1(b).The prediction error is varied between ± 9TECU.

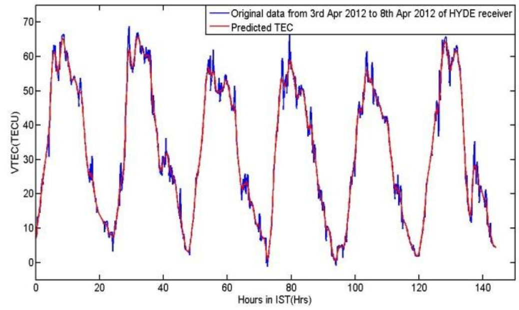

Figure1 (a) six days ahead forecast of VTEC (TECU)for the period 3rd -8th April 2012,at HYDERBAD receiver.

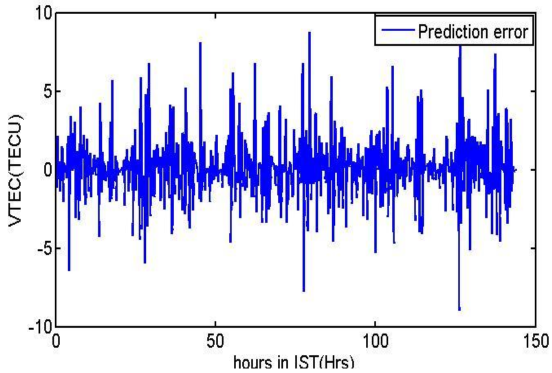

Figure 1 (b) Prediction error.

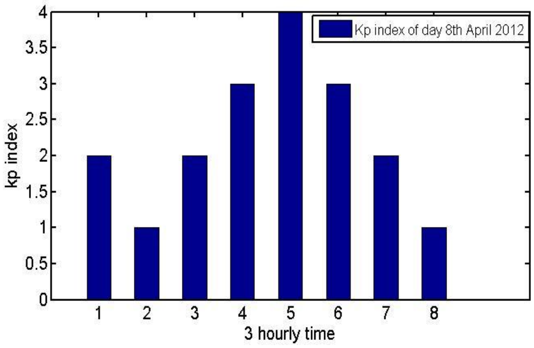

Figure 2a Kp index values for 8th April 2012.

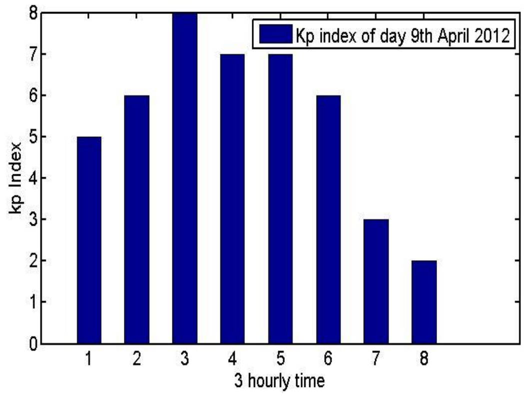

Figure 2b Kp index values for 9th April 2012.

The kp index values (8th and 9th April 2012) are shown in Fig 2.The 8th April 2012 day is considered as quit day and 9th April 2012 day is considered as disturbed day.

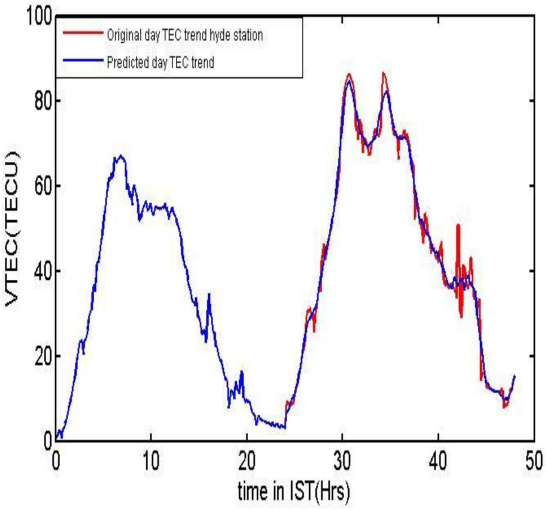

Figure 3 (a) VTEC Prediction of next day (9th April 2012)Using previous day (8thApril 2012) from Hyderabad receiver .

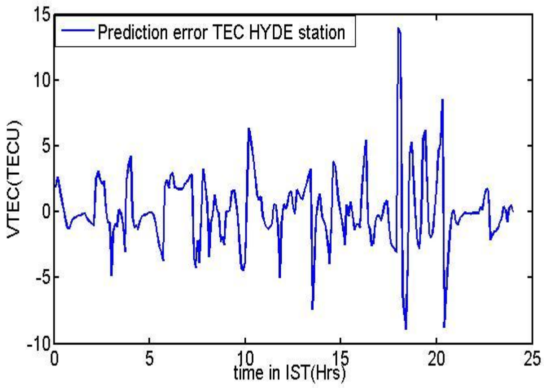

Figure 3(b) Prediction error.

The 8th April 2012, data is used to calculate the covariance values of VTEC time series data, using these covariance values, prediction point is calculated and added to the end of point. The process is repeated for next 24 hours data (9th April 2012) .The forecasted values are compared with nowcasting TEC values shown in Fig (3a).The prediction is varied from 13TECU to _9TECU as can be seen from Fig (3b).

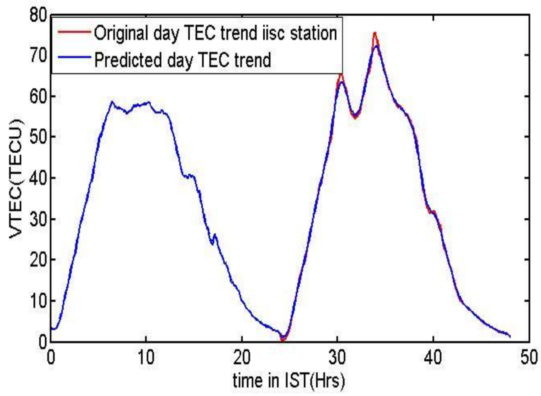

Figure 4 (a) VTEC Prediction of next day using 9th April 2012 data from IISC receiver.

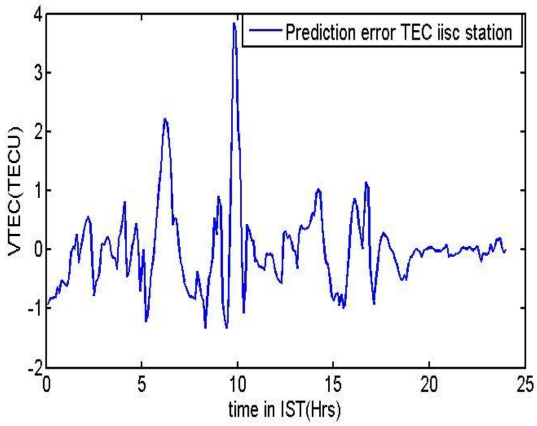

Figure 4 (b) prediction error.

Similar analysis is carried out for Bangalore station. The actual and forecasted TEC values are shown in Fig4 (a).The prediction error is varied from -1 to 4 TECU as shown in Fig4 (b). It is observed that, the prediction error of Bangalore station is less as compared to the prediction error over Hyderabad station data.

V. CONCLUSION

Autocovariance method is one of the popular techniques for analyzing the time series data. Ionosphere TEC variations over low latitude regions are dynamic and highly variable. Autocovariance technique is used to forecast the time series data of TEC values. The preliminary results are obtained using Hyderabad and Bangalore GPS stations data. It is evident from the results that the TEC values are closely following the actual TEC values. More number of stations data over several stations would be useful for forecasting the ionospheric characteristics using the proposed technique in future.

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