ARMA Ionospheric Prediction Model for GAGAN Applications

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Abstract
GAGAN system expected to give high precision positional accuracy to users. As India comes under low latitude region, there is a necessity to understand low latitude ionospheric characteristics in detail to provide ionospheric delay corrections. Integrity is one of the key performance evaluation parameters for GPS position estimation that can be enhanced by forecasting TEC variations along with the real time ionospheric corrections. TEC values are forecasted using Auto Regressive Moving Average (ARMA) model with the help of day to day and seasonal ionospheric variations and sudden atmospheric distributions like magnetic storms, inter-planetary forces. Dual frequency GPS receiver data of K L University, Vaddeswaram station (16.31° N, 80.37° E), India is considered for the analysis. GPS data during (5th January to 28th February, 2013) is extracted and vertical TEC values are estimated using the modified planer fit model. The AR coefficients are estimated using the variance, autoregressive method. Also, MA model coefficients are calculated using regression analysis. Combining both AR and MA models ARMA model with the order p = 2 and q = 4 is selected. The preliminary results show that ARMA model would be an effective tool for developing an early warning ionospheric disturbance system for GAGAN applications.

Keywords
GPS, GAGAN, Ionospheric Error, TEC, ARMA Model

I. Introduction
GPS (Global Positioning System) is a Global Navigation Satellite System (GNSS) composed of a flotilla of satellites, each of which makes two circuits around the Earth every 24 hours to provide 3-Dimensional positioning with global coverage [1]. GPS errors can arise from inaccuracies in the estimate of satellite position and satellite clock correction, tropospheric, ionospheric effects, receiver noise. Stand alone GPS system can not meet the aviation precision approach requirements. Augmentation of GPS is necessary. Satellite Based Augmentation Systems (SBAS) are used to improve the stand alone GPS system performance in terms of position accuracy, availability, integrity and continuity. SBAS developed across the India called as GAGAN (GPS Aided Geo Augmented Navigation), which is jointly planned by the Indian Space Research Organization (ISRO) and Airports Authority of India (AAI) [2]. Within space weather framework, ionospheric Nowcasting and Forecasting, especially received much of the attention as the widely used systems, e.g. HF communication, Earth Observation and satellite positioning and navigation systems are influenced due to the ionospheric time delay error. Hence the determination of the ionospheric error is very important to provide the differential corrections for high precision GPS users [3]. While GPS signal travelling through the ionosphere, the carrier experiences a phase advance and code experiences group delay due to the Total Electron Content (TEC) from satellite to the receiver causing the degradation of the accuracy [4]. Indian master control station estimates the Ionospheric Grid Point (IGP) delays and transmits to the user by Geo Earth Orbit (GEO) satellites [5-6]. Also several Ionospheric models such as planar fit, Kriging, Inverse Distance Weighted (IDW), Spherical Harmonics Functions (SHF) and Minimum Mean Square Error (MMSE) models are implemented for GAGAN [7-8]. TEC are varying with local time, season and solar activity has been studied extensively [9-11]. The high priority is given for the forecasting and modelling of the ionospheric response during geomagnetic storms for the reliable performance radio communications systems under geomagnetically disturbed conditions. Focusing on prediction of the ionosphere, different models are developed based on time series forecasting techniques such as the standard autocorrelation as well as auto-covariance, neural networks, International Reference Ionosphere (IRI) model, Auto Regressive Moving Average (ARMA) [12]. Among all these ARMA performs well in the prediction and also used in the applications such as biological, signal processing, medical fields and statistics fields.

II. ARMA Model
Auto Regressive Moving Average (ARMA) model is also called as Box-Jenkins(Named after two scientists George Box and Gwilym Jenkins). It is a statistical model used for prediction of future values based on past values of time series data. Time series of TEC data is defined as a collection of data in equal interval of time over a period of time. It is a stationary model whose data must have same mean and variance throughout the series of data. ARMA is appropriate when a system is a function of a series of unobserved shocks (the MA part) as well as its own behaviour. The mathematical equations of ARMA model can be written as [13],

\[ x_t = c + \sum_{j=1}^{p} x_{t-j} \phi_j + \epsilon_t \]  

The estimated parameters will be used in time series data into the expression or AR model. The trend which must be similar to the estimated TEC trend or the original TEC trend is obtained. If the obtained TEC trend is not similar to desired trend then the order of matrix to get different no of parameters to p is varied. The above process is done till desire TEC trends obtained. As the order of the model increases the accuracy of the output will be reduced as more no of harmonics will be produced. The order of the parameters must be as low as possible so that accurate prediction can be achieved. Once the output has obtained the MA process begins to improve the quality of the output. Flowchart for ARMA technique implementation steps are given in fig. 1

III. Results and Discussion
The GPS data recorded at K L University, Vaddeswaram GPS receiver (16.31° N, 80.37° E), India is considered for analysis. The processed GPS data contains nine key parameters such as PRN number, latitude, longitude, GPS week number, GPS second of the week, azimuthal angle, elevation angle, slant TEC and vertical TEC. Planar fit ionospheric model is used to estimate vertical TEC values at station coordinates [14]. ARMA model is applied on GPS

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data, which is in non-stationary. The mean is separated form it to become stationary. Then data of six months (5th January to 28th February) are observed for estimation.

The original data used as training data and from that the prediction of next day is done and then it is compared with the available original data. The diurnal variations in TEC are as minimum in the predawn, maximum in the afternoon then decreasing gradually after sunset.

### A. January Data

Fig. 2 shows that in January month maximum VTEC values are about 30 TECU reaches a maximum TEC of 35 TECU. But on 10th and 12th of January VTEC reaches to a maximum value of VTEC 50 and 55 TECU respectively at around 12:00LT. During each day the maximum of VTEC is different indicating high variability. Training data of 30 days are used to predict the 31st Jan, 2013 data. The prediction error is given varying between -4 TECU to 4 TECU.

### B. February Data

Fig. 3 shows that in February month maximum VTEC values are about 38 to 52 TECU. It reaches a maximum TEC of 52 on 12th of February. During each day the maximum of VTEC is different indicating high TEC variability. Training data of 27 days are used to predict the last 28th Feb, 2013 data. The prediction error is given varying between -5 TECU to 5 TECU.

### IV. Seasonal Variation of TEC

The TEC variations during different seasons recorded at KL University, Vaddeswaram. The observation period is divided into 3 seasons, Winter (Jan, Feb), Equinox (Mar, Apr), and summer (May, June). Fig. 4 represents monthly mean of GPS VTEC values. From the above observations, it is evident that the VTEC values are high in equinoctial months than the VTEC values during winter and summer seasons. The seasonal variation of VTEC is directly controlled by thermospheric neutral compositions. During winter season VTEC varies from 35 TECU-55TECU, during equinox varies from 55 TECU-72
V. Conclusion

ARMA Ionospheric forecasted model is a statistical technique of time series TEC data. AR and MA parameters are derived for the orders 2 and 4. It is evident from the results that ARMA model performs better prediction accuracy as compared to measured data. More number of GPS stations data would be useful for developing ionospheric models for understanding low latitude ionosphere behavior.

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References


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