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Ionospheric Modeling and Forecasting Services of GNSS

Yellamma Pachipala, Amarendra K, Puvvada Nagesh, K Sri Rama Vamsi

Abstract: ***The study of ionospheric variability is vital for refining and predicts services of GNSS (Global Navigation Satellite System) applications. The GNSS service provides an explicitly obtainable resource GNSS information, goods and services in support of the earthly reference structure. GNSS is provides an Earth observation, navigation, positioning, timing and other applications that an assistance Society and Science. To investigate the variations in the daily averaged TEC (Total Electron Content) by taking several model components such as solar activity component, geomagnetic activity and periodic components at different latitudes ranging from 10˚N to 26˚N for the year 2018. The presented results would be useful to download, processing and analysis the IGS (International GNSS Service) data. MSSA model can reproduce quite well the observed values of GPS-TEC by utilizing only the first 4 singular modes and constitutes 99% of the total variance. The data is transformed into the singular values which are used for forecasting a noiseless time series. The proposed system results show that higher accuracy is achieved by MSSA (Multivariate Singular Spectrum Analysis) based model. It can also be noted that the training of MSSA is much faster and achieves higher learning accuracy, lowest training time. MSSA is effective even the space weather conditions are active during different solar phase periods.***

Keywords: GNSS, MSSA, International GNSS Service, Global Positioning System, total electron content

I. INTRODUCTION

Now days we usually come across a common acronym named as GNSS (Global Navigational Satellite System).The GNSS became popular in providing the three-Dimensional (3-D) user location and the information regarding latitude, longitude, altitude, velocity and time with help of space-vehicle navigation system. The navigation world has recently driven in contemporary implementations as given below:

a)Global Navigation Systems:

1)USA-GPS (Global Positioning System)
2) USSR-GLONASS
3) ESA-GALILEO
4) China-COMPASS

b) Regional Navigation Systems:

1) India-IRNSS (Indian Regional Satellite System)
2) Japan -QZSS (Quasi Zenith Satellite System) etc.

The GPS is a space based radio satellite Navigation system. It is owned by united state of America (USA). USA has currently has 24 operational space vehicles in its constellation of 6 orbital planes in each four satellites to get a global coverage at altitude of 20,200 km. It allows the users to find their accurate position and location, latitude, longitude and altitude with respect to time. GPS is key to study the Space weather and its related activities [1]. The applications of GPS can find in navigational applications such as in agriculture, geodesy, surveying, transportation and other many scientific and military applications. The accuracy levels of GPS can depend upon many factors [2]. But In spite of high accuracy of GPS, the user can know his accurate position through GPS signals travelling between satellites and receiver with respect to time**.**

GPS is a constellation of satellites which transmits the navigational information in the form of signals [3]. Though it provides the vast information, the GPS signals also face User Equivalent Range Errors (UERE) such as multipath errors, Ionospheric and Tropospheric delays, ephemeris and clock errors etc [4]**.** There is a major probability of errors in broadcasted GPS signals that propagate through the ionosphere and experience several effects proportional to the total number of electrons presented in its path from GPS satellite to receiver.

There is a much probability of errors in GPS signals that propagate through the ionosphere and is proportional to the total number of electrons presented in its path from GPS satellite to receiver [5]. The Ionosphere which is of altitude 66-1000 km is frequently disturbed by local time, location, season and solar activities, and storms [6].The ionosphere is a very huge complex system which is very much imperative and highly relevant to space, modern technologies as well as radio communications [7]. Hence ionosphere study should be done in detail. The various parameters that involved in ionosphere are TEC (Total Electron Content), hmf2, fof2, electron density etc. The main objective in this ionosphere study is how the linear time series model Total Electron Content is reflecting its characteristics on solar activities, geomagnetic activities, and periodic oscillations in the ionosphere.

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* Correspondence Author
Dr Yellamma Pachipala*, Associate Professor, Dept. of CSE, Koneru Lakshmaiah Education Foundation, Vijayawada, A.P INDIA
Email:Pachipala.yamuna@gmail.com
Dr Amarendra K, Professor, Dept. of CSE, Koneru Lakshmaiah Education Foundation, Vijayawada, A.P INDIA
Puvvada Nagesh, Assistant Professor, Dept. of CSE, Koneru Lakshmaiah Education Foundation, Vijayawada, A.P INDIA
K Sri Rama Vamsi, Student, Dept. of CSE, Koneru Lakshmaiah Education Foundation, Vijayawada, A.P INDIA

II. REVIEW CRITERIA

The Nature of ionospheric activity levels can be defined in terms of electron density measuring the total number of electrons in a vertical column of the medium with 1 m2 (one square-meter) cross sectional area and is described as total electron content (TEC). Mathematically 1TECU = $1\times10^{16}\ electrons/m^2$ where TEC can be measured in a units represented in TECU. The physical and the chemical processes which undergoes in the ionosphere are determined by the ionospheric empirical models. Many investigations has been carried out on ionosphere based on the long term trend data of the past observations [8] The efficiency of the most of these empirical models to predict the accuracy of TEC varied with the geographical locations[9]. For example, the low latitude region had proved to be a more difficult of all the regions. As this region is situated near to the anomaly crest region, it is of much concern to all the users for the satellite based navigation and the communication systems. Currently there were no ionospheric models that can predict the TEC accurately in the low latitude regions [10]. It's been mainly implemented on to study and collects the past observations to develop a model of a time series on different factors or variables. Further investigation needs to be done in the low latitude region in predicting the TEC more accurately. There are several factors considered by many researchers to develop an empirical model.

The sun exhales the various levels of solar radiation in various parts of solar atmosphere. This solar UV irradiance plays an important role in the photo chemistry, temperature distribution ad overall balance of lower thermosphere, mesosphere and stratosphere [11]. Previously, solar UV measurements were not available, however in the current year ionospheric research the monthly sunspot number ('Zurich sunspot number') is treated as a fundamental index of a solar activity for ionospheric parameters prediction [12]. However many efforts have been made to develop a better solar activity index for measurement of solar activity levels.

Ionosphere

Height at which the ionosphere starts to become sensible is about 50 km and it reaches as high as about 1000 km. In fact the upper boundary of the ionosphere is not well defined since it can be interpreted as the electron densities thinning into the plasma sphere (or proton sphere) and subsequently the interplanetary plasma [Langley, 1996]. Depends on density of electrons, rate of absorption of sun radiation and composite gaseous present in the ionosphere layers are divided as D (50 to 90 km), E (90-150km), F (F1, F2) layers. The existence of these layers is depended on solar radiation only. The presences of free electrons are directly proportional to the absorption of sun radiation. Hence the F (F2) layer will have more number of electrons. Thus the F2 is most important Ionosphere layer, which is presented at 250-400 km, is of more important as it will not allow the electromagnetic radiations (HF propagation).

III. METHODOLOGY

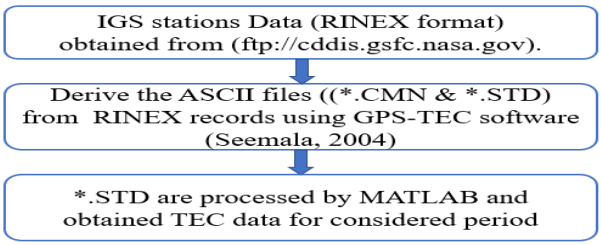

Figure 1:Flow chart of the proposed work

Figure 1 shows the total flowchart of the goal one. The stream graph in the fig. totally clarifies the post-handling of TEC information. System got RINEX information from the GPS station are brought into GPS application software This product changes over the RINEX documents into the ASCII files (CMN,STD,TEC images).The point by point clarification are referenced in the writing survey segment. After post-handling, VTEC qualities will be gotten. The Matlab contents are set up to the watched information for plotting in the Matlab. These plots are helpful for contrasting and Modelled TEC esteems which will be talked about in the following area.

The inclination (Slant Total Electron Content) determined from stage and gathering TEC which is contaminated with the beneficiary and satellite predispositions. Consequently, wanted inclination TEC = STEC + BRx + BRich + Bsat where BRx, BRich, Bsat are recipient predisposition, collector between station inclination and satellite inclinations.

IV. RESULT AND DISCUSSION

To investigate the ionospheric variability GPS-TEC observed data (20 years) is considered over Japan region at the Grid Point (134.05 E and 34.95 N) covering 23rd solar cycle (1997-2008) and 24th solar cycle (2009-2016).

The annually mean experimental TEC movement stay substantially to MSSA model TEC trend (Figure 2). This is mainly due to the coefficients of MSSA which are directly derived from the original GPS-TEC data decomposition. An estimated RMSD(Root Mean Square Deviation) for experimental TEC and model TEC in the period 2000-2011 (Solar cycle 23) is 0.32 TECU, which is quite high compared to the RMSD value 0.27 TECU during period 2010-2018 (solar cycle 24). During LSA (Low Solar Activity) years the residual error values are low when compared to HAS (High Solar Activity) years

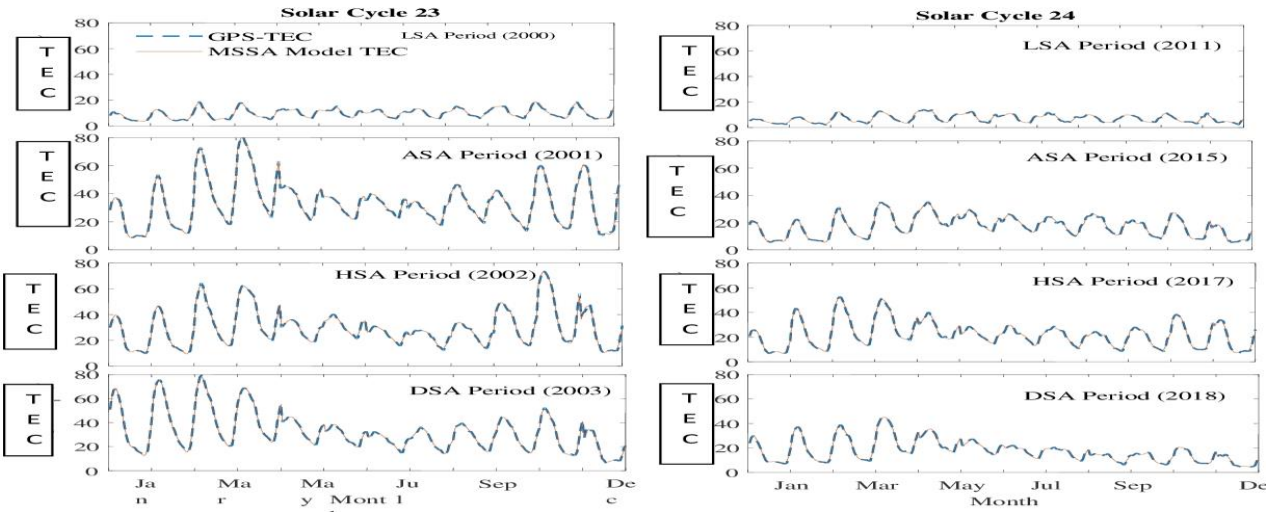

Figure 2.The mean TEC values of MSSA and observed TEC model values in LSA, HSA, ASA and DSA periods covering 23 and 24 solar cycles(monthly).

The similarity among the MSSA model TEC and an observed GPS-TEC in LSA, HSA period, Ascending Solar Activity (ASA) period and Descending Solar Activity (DSA) period during 23 and 24 solar cycles is illustrated in Fig. 6 exhibits the magnitude variations in GPS-TEC during equinoctial months which are evidently distinct during solstice months. Further, the TEC values in equinox months are much closer to TEC values in solstice months during LSA periods (2000-2011). During the different phases of solar activity, the overall GPS-TEC trends and MSSA model trends are identical. Further, it can be observed that the most of the maximum values from equinoctial months and most of the minimum ones from solstices months confirming the outstanding semi-annual variation.

Variations between the Model Values and GPS-TEC during LSA, HSA, ASA and DSA periods in 23 and 24 Solar Cycles are represented in Table I. This can be observed that the model monthly mean RMSD values are less when monitored to the observed GPS-TEC values, which indicates that the variations are accurately represented by the MSSA. In addition, during HSA years the RMSD values are greater than in LSA years. This aspect has been examined for different ionospheric parameters in various studies. The seasonal deviations are divided into four types spring, summer, autumn
and winter seasons

Table I: Variations Between The Model Values And GPS-TEC During LSA, HSA, ASA AND DSA phase in 23 and 24 Solar Cycles

Solar Cycle- 23		Solar Cycle- 24	
Solar Activity Period	RMSD TECU	Solar Activity Period	RMSD TECU
LSA (2000)	0.97	LSA (2011)	0.61
ASA (2001)	0.92	ASA (2015)	0.67
HSA (2002)	0.88	HSA (2017)	0.56
DSA (2003)	0.81	DSA (2018)	0.52

Table. II. Seasonal deviations between the Model values with GPS-TEC values under LSA periods, HSA Period, ASA period and DSA period during 23 and 24 solar cycles

Seasons	Solar Cycle 23				Solar Cycle 24			
	LSA 2000	ASA 2001	HSA 2002	DSA 2003	LSA 2011	ASA 2015	HSA 2017	DSA 2018
Spring	0.33	0.26	0.73	0.46	0.72	0.53	0.72	0.54
Summer	0.32	0.25	0.70	0.44	0.80	0.58	0.71	0.43
Autumn	0.30	0.20	0.9	0.46	0.80	0.60	0.63	0.39
Winter	0.34	0.34	0.97	0.58	0.75	0.60	0.74	0.54

The Table II shows seasonal deviations between GPS-TEC values and model values during 23 and 24 solar cycles under LSA, HSA, ASA and DSA periods. During LSA period it has been noticed from Table II the minimum deviation values are 0.30 and 0.72 for the solar cycle 23 and 24 respectively.

These observations are made in the autumn season for solar cycle 23 and spring for solar cycle 24, while the maximum values 0.34 was observed in winter for solar cycle 23 and0.80 was observed in summer for the solar cycle 24. Similarly, the values for the periods HSA, ASA and DSA were illustrated in Table II. From the table containing LSA periods, we can notice the model TEC values and observed TEC values are closer and comparable. The seasonal variation of TEC is in the control of neutral composition. One important feature is noting that the deviation error of MSSA model in summer is lesser than in winter during HSA years even though summer has smaller Zenith angle. This aspect is similar with seasonal anomaly of ionosphere, which can be applied to summer-to-winter neutral circulation in HSA years. The results agree well with the past reports of A et al.

In geomagnetic storm events, modeling of TEC is important for better understanding the response as well as it is used for ionospheric storm effects characterization. To model the TEC during geomagnetic storm conditions applied the global EoF model. The earlier model does not perform well during severe storms (−200 nT ≥Dst> −350 nT). To accomplish better performance during severe events, Uwamahoro and Habarulema applied a nonlinear technique; this is Neural Networks (NNs). As for the daily indices F10.7 and Ap values are used as inputs, which is the reason for some storms, the EOF model cannot capture negative and positive TEC responses. These indices represent the daily average level of solar activity and geomagnetic activity, while features of geomagnetic storms are varying short. In addition, the NN model accuracy is high by estimating the magnitude of TEC with respect to the non-significant TEC response of the ionosphere. Nevertheless, the NN model may not execute always well. Hidden node number is one of the reasons for its inability to capture the short-term features and it also affects the prediction capability of the NN. During magnetic storms, the validation of the MSSA model should also be considered.

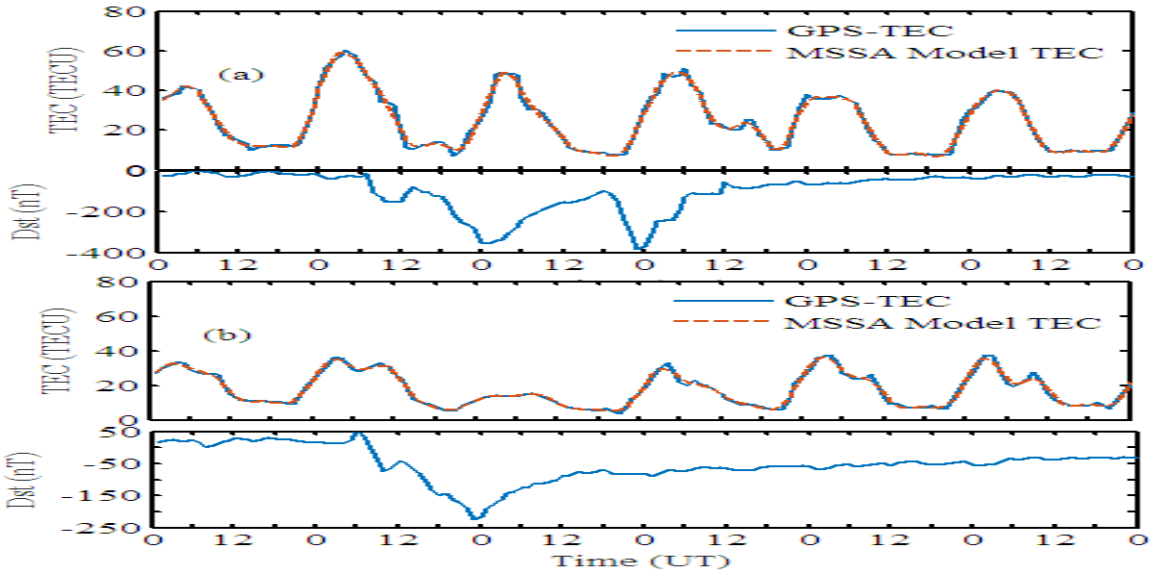

Figure 3: Comparison of GPS-TEC and MSSA model values during 2004 to 2018 during solar cycle 23 and 24

The Figure 3 has shown the evaluation of GPS-TEC and MSSA model on the year 2004 and 2018. GPS-TEC trend is followed by MSSA model during the recovery phase of 5 days. MSSA model estimates the TEC scale in gale period. In addition, the MSSA model followed the negative TEC response in storm hours. The RMSE between GPS-TEC and MSSA modeled TEC values during 30th October 2004 was 1.19, Figure 3 shows the comparison of GPS-TEC and MSSA model values in the storm event 19th march, 2018 during 24th solar cycle. During the storm period on 19th march 2018 (Dst<206 nT) the MSSA model capturing the GPS-TEC response shows a long recovery phase of about 3 days. MSSA model recorded the TEC enhancement and depletions during recovery phase and MSSA model followed the respective negative TEC response during 16:00-23:00 hrs. The RMSE between GPS-TEC and MSSA modelled TEC values during 30th March 2015 during 24th solar cycle is 1.16. For TEC modeling, it is also found that the MSSA model predicts TEC enhancements and depletions better during severe geomagnetic storm condition.

V. CONCLUSION

In the present paper, we have established multivariate singular spectrum analysis (MSSA) model which accounts the influences of solar and geomagnetic activities. To accomplish the maximum capacity of MSSA, we have considered a VG approach while determining the covariance and the improvements in noise reduction. MSSA model can reproduce quite well the observed values of GPS-TEC by utilizing only the first 4 singular modes and constitutes 99% of the total variance. The MSSA model values agree quite well with the observed values, having correlation coefficients about 0.90, and RMSD 0.9 for the year (2000-2018). The proposed MSSA achieves high level now casting illustration with solar cycle (solar phase), seasonal, and storm time dependences. The data is transformed into the singular values which are used for forecasting a noiseless time series. The TEC prediction is then performed. The results show that higher accuracy is achieved by MSSA based model. It can also be noted that the training of MSSA is much faster and achieves higher learning accuracy, lowest training time. MSSA is effective even the space weather conditions are active during different solar phase periods. With the ability, future works involves in obtaining the better components tracking and improving the new proposed algorithm.

This could lead to the more advanced applications development for near real-time scenarios.

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