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Empirical Modeling Of ITEC Parameter At Mid Latitude

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Abstract- An empirical model of ionospheric total electron content (ITEC) for mid latitude location, grahmstown during the period of January 2006 to December 2009 has been developed by using harmonic analysis. The hourly value of ITEC has been used in this current study. A set of 81 coefficients of zero and first four orders were resolved using harmonic analysis, the solar activity dependence of the amplitude. The analysis reveals that the strongest connection of ITEC variations related with solar flux. In present study the diurnal variation of modeled and observed ITEC values for three month January, March and June during low solar activity period. It has been found that the agreement between observed, modeled and IRI values are rather good with maximum deviation ≤ ±15% during the month of June**.**

Index Terms- Solar flux, Harmonic analysis, IRI model, empirical modeling, ITEC.

1. INTRODUCTION

Signal delay due to ionosphere is directly proportional to the number of free electron in the ionosphere so the total ionospheric electron content (ITEC) play an important role to correct ionospheric delay; hence, the performance levels of different earlier versions of the IRI model with respect to predicting TEC have been investigated in various regions under different solar activity conditions studied by various groups [1-14]. The distribution and characteristics of TEC over low, mid and high latitude regions have been investigated by a number of researchers [15-22]. The latitudinal variation of the TEC is mostly dictated by the phenomenon of EIA [23,24]. An ionospheric model can be either a first-principles-based physics model which is developed from an exact mathematical analysis of laws of physics and based on numerical solution of the spatial temporal equations, or an empirical model which refers to any type of modeling based on empirical observations.[25-28] found that Different types of variability in ionosphere are subject to a number of interconnecting drivers which can be basically characterized as follows: (a) solar ionizing radiation; (b) geomagnetic activity; and (c) meteorological influences. Empirical modeling is actually fitting of investigative functions to selected database, as the accuracy is assessed by standard deviation of the models from the data. Therefore, the precision of the models depends on two factors: decision of proper database and choosing analytical expression that accurately explain the real variations of ionospheric parameters. The proper adjustments of these two factors are the main challenge of the presented empirical models. The IRI model is a widely used empirical model for ionospheric predictions [29,30]. It can be used to estimate the values of electron density, electron temperature, ion temperature, ion composition, and TEC at altitudes ranging from around 50 to 2000 km at a specific location, time, and day. The model is constantly updated when new data and new techniques are obtainable; this process has resulted in several versions of the model. The first version was released in 1978 [31] and was followed by several progressively improved versions in 1986, 1990, 1995, 2001, and 2006. Recently, the IRI model was upgraded to the IRI-2012 version [32, 33], which improves significantly on the representations of electron density, the description of electron temperature and ion composition, and bottom-side thickness. Empirical ionospheric models are generally suitable for application leaning research and operational services, like ionospheric forecasting. Whereas all models are based on the linear regression approach, the correct relation between drivers and response parameters is still a state-of-art solution. The most important progression of contemporary models is the introduction of deferred response of ionosphere to the driver forcing. It is significant when using geomagnetic indices and solar wind parameters as drivers. At equal other conditions, a suitable time delayed reaction can increase significantly the accuracy of model and its predictions.

2. DATA AND METHODLOGY

In the present work we have used hourly value of ITEC observed by Ionosonde obtained from Space Physics Interactive data resource (SPIDR) Network (http://spidr.ngdc.noaa.gov.), we have develop an empirical model of ITEC, for low solar activity using observed value of ITEC during the year January 2006 to December 2009 (which is the decline phase of solar activity) for Grahmstown (33^0 S-27^0E).

ITEC being cyclic in nature it can be denoted by a periodic function F (t) like as following equation.

$$F(t) = A_0 + \Sigma\, A_n \operatorname{Sin}(n\theta + \phi_n) \qquad (1)$$

Where t=1, 2……24, θ is 360t/24 radians, ϕ_n is phase angle and n is number of harmonics.

Expending the Equation number (1) we get the following function.

$$F(t) = A_0 + \Sigma\, (A_n \operatorname{Sin} n\theta \operatorname{Cos} \phi_n + A_n \operatorname{Cos} n\theta \operatorname{Sin} \phi_n) \qquad (2)$$

Where n= 1, 2, 3, 4,

F (t) is single valued periodic functions, A_0 daily mean, while (A_1, A_2, A_3, A_4,) are the amplitude and (ϕ_1, ϕ_2, ϕ_3, ϕ_4) are the phases,

Substituting $A_n \operatorname{Cos} \phi_n = a_n$ and $A_n \operatorname{Sin} \phi_n = b_n$
We get

$$A_n = [a^2_n + b^2_n]^{1/2} \qquad (3)$$

And

$$\operatorname{Tan} \phi_n = b_n/a_n \qquad (4)$$

The amplitude A_n and phase ϕ_n of n^{th} harmonic may be obtained from equation (3) and (4), correspondingly.

We did harmonic analysis of monthly average hourly ITEC values for finding the daily mean (A_0), amplitude (A_1, A_2, A_3, A_4,) and phase (ϕ_1, ϕ_2, ϕ_3, ϕ_4) for all month of the data set and find the amplitude and phase of the n^{th} harmonic are averaged each month for each year of the entire period of study,(January, February,…….December). Again we did the harmonic analysis for the above averaged values to get the 81 coefficient, (listed in Table 1).

Table 1
81 Harmonic Coefficients

	A00	A01	A02	A03	A04	p01	p02	p03	p
A0	**4.812**	**1.957**	**0.523**	**0.079**	**0.115**	**0.266**	**3.030**	**2.220**	**0.**
A1	**4.573**	**1.355**	**0.742**	**0.090**	**0.312**	**0.079**	**-2.782**	**-0.799**	**0.**
A2	**1.165**	**0.364**	**0.310**	**0.028**	**0.095**	**-1.765**	**-2.469**	**-0.425**	**0.**
A3	**0.316**	**0.022**	**0.052**	**0.063**	**0.035**	**-1.461**	**-2.116**	**0.616**	**1.**
A4	**0.318**	**0.137**	**0.126**	**0.043**	**0.057**	**-2.619**	**1.952**	**0.980**	**0.**
P1	**2.981**	**0.069**	**0.008**	**0.028**	**0.017**	**-2.614**	**-0.371**	**-0.481**	**1.**
P2	**-0.084**	**0.224**	**0.221**	**0.084**	**0.124**	**0.430**	**1.210**	**2.538**	**2.**
P3	**-0.236**	**0.290**	**0.249**	**0.329**	**0.147**	**2.643**	**1.157**	**0.854**	**1.**
P4	**0.503**	**2.341**	**0.835**	**0.615**	**0.561**	**-2.307**	**1.536**	**2.813**	**0.**

We have calculated the modeled mean A_0 by using the following equation.

$$\begin{aligned}(A_0)_{mod} = {} & A_{00} + A_{01} \cos(2\pi M/12 + \phi_{01}) \\ & + A_{02} \cos(2\pi M/6 + \phi_{02}) \\ & + A_{03} \cos(2\pi M/4 + \phi_{03}) \\ & + A_{04} \cos(2\pi M/3 + \phi_{04}) \qquad (5)\end{aligned}$$

Similarly the other coefficients $A_{1\ mod}$, $A_{2\ mod}$…, A_{4mod} can be found from corresponding constants.

The effect of solar flux is calculated in the modeled coefficient using regression coefficient.

$$(\grave{A}_n)_{mod} = (A_n)_{mod}\,(\, m\, S + C\,)/5 \qquad (6)$$

S= Solar Flux and m and C, regression coefficient are listed in Table-2.

Table 2
Linear Regression Coefficients of SF and ITEC.

ITEC Coefficients	m	C
A0	**0.1141**	**-3.7947**
A1	**0.1626**	**-7.7449**
A2	**0.0709**	**-4.2073**
A3	**0.0066**	**-0.1851**
A4	**0.0096**	**-0.4165**

Empirical Model:

The diurnal behavior mean value for the period of January 2006 to December 2009 is determined by the following equation

$$\begin{aligned}ITEC(t) = {} & (\grave{A}_0)_{mod} + (\grave{A}_1)_{mod} \operatorname{Cos}(2\pi t/24 + \phi_{1mod}) \\ & + (\grave{A}_2)_{mod} \operatorname{Cos}(2\pi t/12 + \phi_{2mod})\end{aligned}$$

$$+ (\grave{A}_{3})_{mod}\ \mathrm{Cos}(2\pi t/8 + \phi_{3mod})$$
$$+ (\grave{A}_{4})_{mod}\ \mathrm{Cos}(2\pi t/6 + \phi_{4mod}) \qquad (7)$$

Where t is local time (1….24 hours

3. RESULTS AND DISCUSSION

3.1 RESULT

In this current study the result obtained on the large scale fluctuations in ITEC is considered from January 2006 to December 2009. Evaluated result also compare with IRI model-2016 .

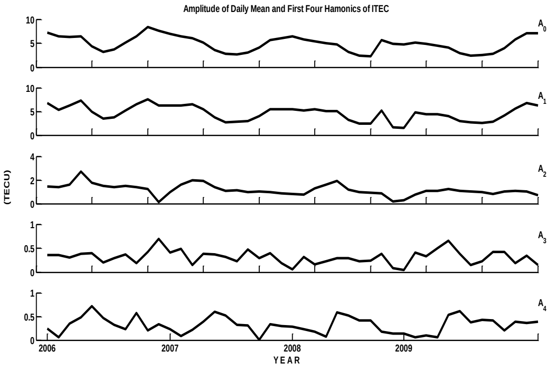

Figure-1 Amplitude of Daily mean and first harmonics of ITEC

Figure 1 shows the yearly variation monthly mean values of daily mean (A_0) and amplitude of first four harmonics (A_1, A_2, A_3, and A_4) get there maximum value 7.5 during 2007. The daily mean value found to be of the same order as the first order harmonic component, contrary to the observations from mid latitude location Grahmstown (33^0S-27^0E), A_0 is about an order of magnitude higher than A_1[34]. The ratio of first order to diurnal mean is around 0.80, while that of the first harmonic to second, third and fourth harmonic around 0.37, 0.11 and 0.09, there by showing the predominance of the diurnal component.

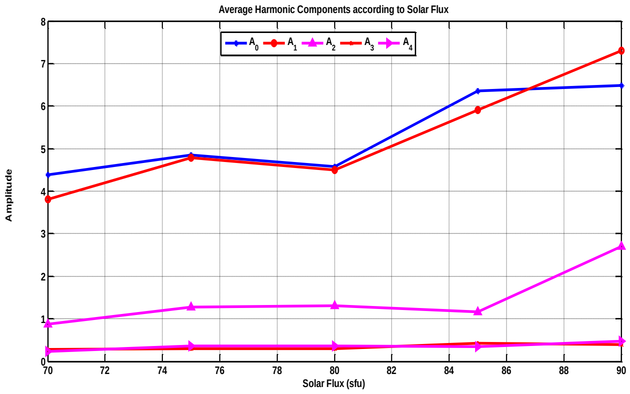

Figure-2 Average Harmonic Component According to Solar Flux

Figure-2 shows the solar activity dependence of the amplitude ($A_{0,}$ $A_{1,}$ $A_{2,}$ A_3 and A_4). The solar flux has been used as a diagnostic tool for representing the label of solar activity. Respective average of harmonic has been calculated. Figure shows that the strongest correlation of ITEC variations associated with solar flux seen in A_0 and A_1.

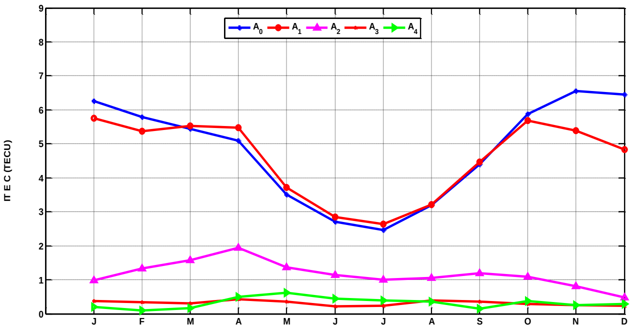

Figure-3(a) Seasonal Variation of Average Harmonic Component

Figure-3(a) shows the seasonal dependence of average harmonic coefficients is more clearly brought out for amplitudes ($A_{0,}$ $A_{1,}$ $A_{2,}$ A_3 and A_4). Here the average of each harmonic component for all the months we calculated separately and plotted against the corresponding month. It make known the seasonal variation of harmonic coefficients $A_{0,}$ $A_{1,}$ $A_{2,}$ A_3 and A_4 showing the maximum value of about 6.5×10^{16}el/m^2 during winter than equinox about 5.3×10^{16}el/m^2 and minimum value of about 2.3×10^{16}el/m^2 during summer. Through the seasonal variations of monthly mean values of the harmonic coefficient $A_{0,}$ $A_{1,}$ $A_{2,}$ A_3 and $A_{4,}$ where $A_{0,}$ $A_{1,}$ $A_{2,}$ are predominant, A_3 and A_4 shows the same trend but have minimum value. The harmonic coefficient $A_1=5.7\times10^{16}$el/m^2 and $A_2=1.8\times10^{16}$el/m^2 shows the maximum value during equinox. From figure-3(b) Modeled coefficient A_0 and A_1 shows higher value 6.5×10^{16}el/m^2 and 5.7×10^{16}el/m^2 during equinox than winter , and lower value in summer where 2.4×10^{16}el/m^2 and 2.6×10^{16}el/m^2.

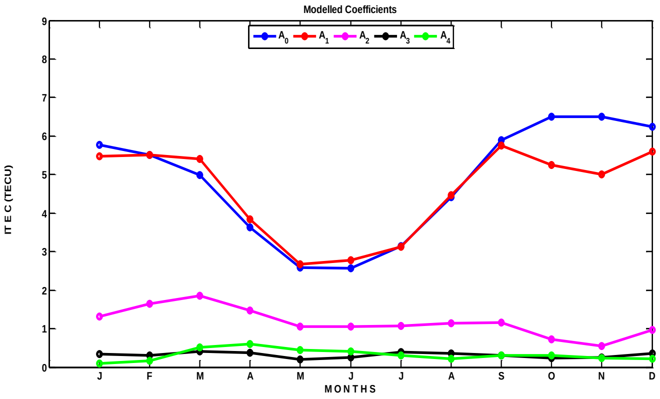

Figure 3(b) modelled coefficients

Figure-4, 5 and 6 shows the diurnal variation of modeled and observed ITEC values for three months January, March and June representing, Winter, Equinox and Summer seasons, during low solar activity period. It has been found that the agreement between observed, modeled and IRI values are rather good with maximum deviation ≤15% during the month of June. In general the IRI value underestimates observed value. From figure-4, during January2006, 2008 and 2009 the IRI-2016 modeled value is low as compare to both the observed and modeled values. But during January 2007 modeled value is higher than the observed and IRI-2016 modeled value at 12 hour LT.

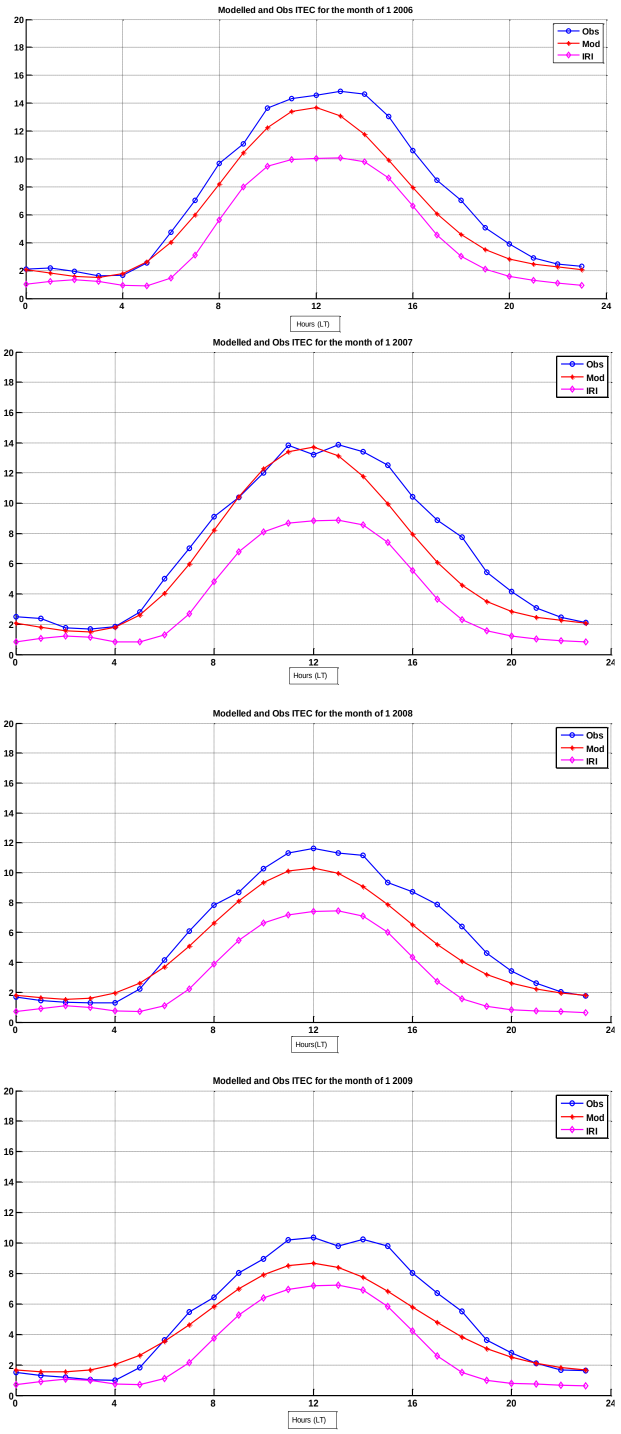

Figure-4 diurnal variation of modeled and observed ITEC values for January

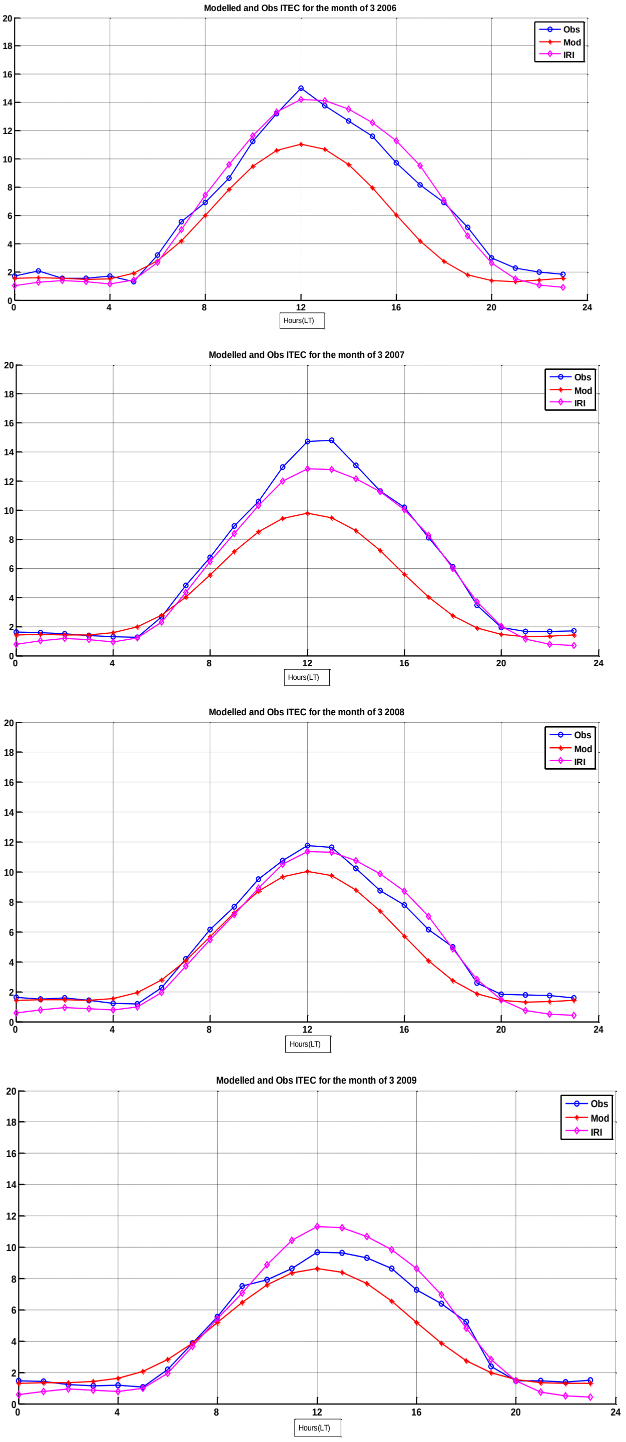

Figure-5 diurnal Variation of Modeled and observed ITEC Values for March

From figure-5, during the month of March in 2006, 2007 and 2008, observed value is higher than the both IRI and model value at 12 hour LT, but in year 2009 the IRI modeled value is higher than the both observed ITEC and modeled values.

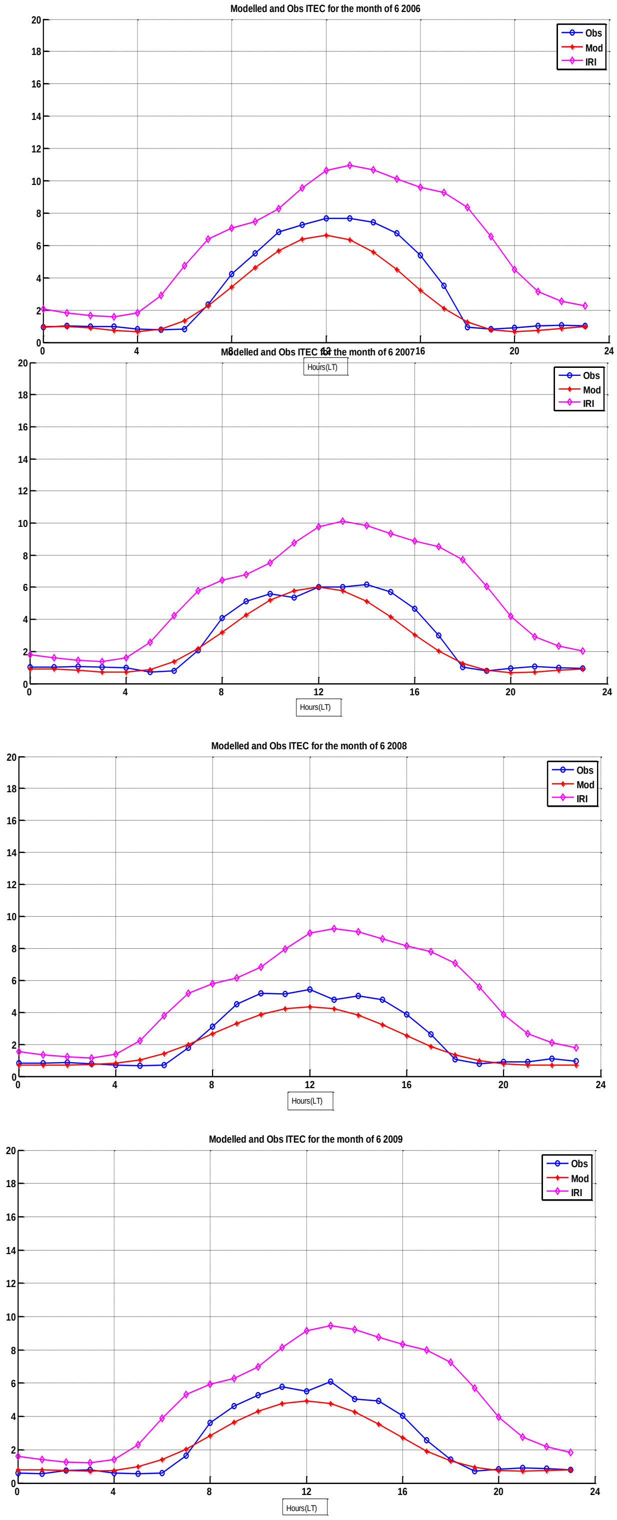

Figure-6 diurnal variation of modeled and observed ITEC Values June

Figure-6 mainly during the month of June agreement between the modeled value and observed value is notable where IRI modeled value is higher than both the values. Dependency of solar flux is visible in summer because IRI-modeled value is high as compare to the both observed value and modeled value.

3.2 DISCOSSION

This study present a strong solar activity dependence of monthly mean of daily mean (A_0) and the first four harmonic coefficient (A_0, A_1, A_2, A_3, A_4) which is an agreement in other studies [34] study the three month representation of three seasons at high, mid and low sun spot year. They found that the agreement between observed and modeled IEC values is rather good with maximum deviation ≤±15% for the duration of February. They also found that the IEC to high when R_z is low and when R_z is high the peak been shifted to two hours later. Mainly in the month of May the modeled and observed value is remarkable. But in the month of September the modeled IEC value are found to be enhanced.

An empirical model using TEC data at low latitude station has been developed by [35]. They conclude that the model strongly depends on the sun spot number. The harmonic component derived from the 81 coefficient scaled by this property. The modeled TEC value generally an agreement with the observed value, for all season and all levels of solar activity; the maximum deviation being limited ≤±15%. The daily mean and harmonic coefficient increases with solar activity up to sun spot number 170 and thereafter decreases exhibiting the saturation affect the monthly mean value of the daily mean and the harmonic coefficients exhibit semi- annual variations with equinoxial maxima and summer minima. Our study shows maximum value during winter than equinox and minimum during summer. [36] calculated the ionospheric TEC at the mid-latitude station in the northern hemisphere according to GPS observations in a year with high solar activity (2013) and in a year with low solar activity (2009). Then, they analyzed the diurnal variation, monthly variation, and solar dependence of the TEC time series. They found TEC value normally enhanced in the period of 04:00 to 06:00 h LT in all seasons and was maximized in the period of 12:00 to16:00 h LT. This value improved earlier during the June solstice. Our result shows the good agreement with them. [37,4,38] it has been well-known by him that past studies revealed that global models such as IRI, PIM, SLIM, and SUPIM in general do not exactly signify TEC variations near the anomaly crest regions. This necessitates the development of station-specific regional models of ionospheric parameters [39-42]. [43] have shown that the IRI overestimates TEC during low solar activity and underestimates it in high solar activity at the crest of the anomaly both in the Indian and East Asian longitude sectors. The electron density have compared by [44] they found that the IRI predictions compare well with observation during hours of minimum (02:00–08:00 LT) ionization during equinox and the December solstice, but strongly disagree during hours of maximum ionization (15:00 LT). They also reported that the IRI underestimates the observed electron density at 600 km altitude (N600) during equinox and winter by 50% and 60%, respectively, and overestimates the observed density by as much as 150% in summer. The dissimilarity was found to be maximum in equinox and minimum in summer. [45] Model based on arithmetical analyses on a long-term (1980–1990) database of TEC from Calcutta situated near the northern crest of the EIA in the Indian zone. The diurnal TEC dependences on solar ionizing flux (F10.7), equatorial electrodynamics (EEJ), season, and local time were analyzed to build up the model using linear, non-linear, and multiple-regression analyses.

4. CONCLUSION

In this study we have developed an empirical model using ITEC values during the period of January 2006 to December 2009 at Grahmstown, a mid latitude station. A set of 81 coefficients of zero and first four orders were determined using harmonic analysis, the solar activity dependence of the amplitude (A_0, A_1, A_2, A_3 and A_4). The solar flux has been used as a diagnostic tool for representing the label of solar activity. Study shows that the strongest correlation of ITEC variations related with solar flux. In present study the diurnal variation of modeled and observed ITEC values for three month January, March and June during low solar activity period. It has been found that the agreement between observed, modeled and IRI values are rather good with maximum deviation ≤±15% during the month of June. The seasonal variation of harmonic coefficients A_0, A_1, A_2, A_3 and A_4 showing the maximum value during winter than equinox and minimum value during summer. Through the seasonal variations of monthly mean values of the harmonic coefficient A_0, A_1, A_2, A_3 and A_4, where A_0, A_1, A_2, are predominant, A_3 and A_4 shows the same trend but have minimum value. The harmonic coefficient A_1 and A_2 shows the maximum value for the duration of equinox. Our model gives the best results in summer season. Results showed that the IRI-2016 model can reveal the climatic characteristics and solar activity dependence of ionospheric ITEC.

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