EMPIRICAL MODELING OF foF2

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ABSTRACT: *This paper presents the empirical modelling of foF2 at low latitude station Jicamarca (12^0 S, 76.90^0W) during high solar activity period of 23rd and 24th solar cycle. To develop the model hourly value of foF2 are collected from the site NGDC Space Physics Interactive data Resource (SPIDR) website (http://spidr.ngdc.noaa.gov). Diurnal variation is expressed by Fourier expansion of Cosine and sine function with period of 24 hours. To describe the solar activity effect, we established relationship between foF2 and sunspot number R by linear fitting method. The Second Degree Regression is applied to make improvement & the quadratic relationship between sunspot number R & foF2. We found that model and observed value of foF2 matched during sun set hours, but at the time of sunrise, there is some deviation between model and observed value of foF2. So model requires an improvement. Solar activity relation between foF2 and sunspot number, nonlinear dependent is observed.*

Keywords-Empirical, Fourier, Diurnal, Solar activity, Sun spot number.

I Introduction

The ionosphere has amazing role in radio communication, navigation and surveillance, early warning etc. There are three facts in communication which cannot deny:
Safety: The value of ionosphere prediction in lives is inestimable,
Commercial: It is trade-off between costs and benefits in future,
Personal: personal important is a convenience.

High frequency radio communications are sensitive to the time of day, season, to the 11- year solar cycle solar flares and geomagnetic storm, so it is required to predict optimum radio frequencies that could be used to HF communication. By considering the importance of prediction, different modeling of ionosphere parameters is done, in which empirical modeling is one of them. Empirical modeling is based on accumulated data of different parameters like critical frequencies (foF2), altitude of peak concentration (hmF2) etc. These models obtain logical ionospheric variation from observed data and provide information about ionospheric parameters. Empirical models play amazing role in all parts of the Sun and Earth environment. Brown et al. (1991) identified and evaluated the six publicly available ionospheric models which predict total electron content. To evaluate the usefulness of the models they collected TEC data from polar meter measurements at several locations around the world. The six models are briefly discussed below:

Bent Model: Bent model (Llewellyn and Bent 1973, Bent et al. 1976) was developed by Rodney Bent and others for Trans ionospheric propagation use. This model requires two solar activity indices such as smoothed Zurich sunspot number and smoothing observed 10.7 cm solar flux.

Fully analytic ionospheric model: This modeled was developed by David Anderson and others as a computationally fast low and mid latitude F-region. It requires smoothing Zurich sunspot numbers for its computations.

Ionospheric conductivity and electron density model: This model was developed H.W. Kroehl, T.F. Tascione and others for the Air force. It uses the URSI-88 coefficients to determine foF2 and hmF2. Its latitude range is 30^0 N to 80^0 N geographic. It requires an effective sunspot number and an effective auroral Q index.

International Reference Ionosphere Model: IRI is widely used ionosphere modeled is recognized as standard specification of ionosphere parameters by committee on space research (COSPAR). IRI uses CCIR coefficient to determine foF2 and hmF2. It requires 12 month running mean Zurich sunspot numbers.

Penn State Model: This model is developed by John Nisbet and Colleagues. It uses National Telecommunications and information administration (NTIA) coefficients to determine foF2.

Hybrid model : This model uses the URSI-88 coefficients to calculate foF2 and hmF2 and Daman-Hartranft-Ramsay (DHR). Hybrid model is given byT. Daman and others to calculate an electron density profile. It requires an effective sunspot number and an effective Auroral Q index.

V. N. Shubin (2017) developed a global empirical model of the critical frequency of the ionospheric *F*2-layer.This model is SDMF2 (Satellite and Digisonde Data Model) of the *F*2 layer for quiet geomagnetic conditions ($Kp < 3$). Parameters used in this are the geographical coordinates, UT, day, month, year, and the integral index *F*10.7 (*day*, $\tau = 0.96$) of solar activity for a given day. They Legendre method for the spatial expansion of *foF*2 monthly medians to 12 in latitude and 8 in longitudes of spherical harmonics were applied. Obtained spatial coefficients have been expanded by the Fourier method in three spherical harmonics with respect to UT. The saturation effect of critical frequency of the *F*2-layer at high solar activity was expressed in the SDMF2 model by *foF*2 as a logarithmic function of *F*10.7 (*day*, $\tau = 0.96$). They observed difference between the SDMF2 and IRI models is a maximum at low solar activity as well as in the Southern Hemisphere and in the oceans. Test is done on the basis of ground-based and satellite data has indicated that the SDMF2 model is more accurate than the IRI model.

Ivan Kutiev (2003) has done empirical modeling of global ionospheric foF2 response to geomagnetic activity. They expanded the previously developed mid latitude model, providing the relative deviation of foF2 from its monthly median value as a function of local time and Kp, to the global scale. For this purpose they selected 55 ionosondes stations, having at least 11 years of continuous, the model was applied to the data from each station separately. Data from each station were arranged into 12-month bins, every bin containing all the collected hourly data within the respective month of the year. The model regarded as the distribution of the relative deviation along the local time at any fixed moment as composed of a diurnal and a semidiurnal wave, expressed by five parameters: daily mean diurnal and semidiurnal amplitudes and phases. The model expression is scaled by a modified function of Kp, which reflects the delayed reaction of foF2 to Kp changes. The model parameters are calculated by fitting the model expression to the data in each bin. And their distribution along the geomagnetic latitude is obtained in three longitude sectors, North America-South America, Europe-Africa, and East Asia Australia. The seasonal symmetry of model parameters in the Northern and Southern Hemispheres, is acceptable, allows the use of parameter values from both hemispheres in obtaining their latitudinal profiles. To construct the global distribution of each of the model parameters, the respective latitudinal profiles of three sectors were averaged and approximated by analytical expression.

II Data and Method

For developing the model foF2 ionospheric parameter, foF2 & sun spot numbers are collected from the site NGDC Space Physics Interactive data Resource (SPIDR) website (http://spidr.ngdc.noaa.gov) for period of solar cycle for year 2002 and 2014 at low latitude station Jicamarca (120S, 76.90W; dip 0.280). Diurnal variation can be expressed Fourier expansion of Cosine and sine function with period of 24 hours.

$$foF2_{(h,m)} = A_0 + \sum A_n \cos n\theta + B_n \sin n\theta \qquad (1)$$

Where A_0 A_n and B_n are called Fourier constants.

$\theta = (360\times t)/24$ degree

t = Local Standard Time

n = Number of harmonics (n = 1, 2, 3----)

To describe the solar activity effect, we use relationship between foF2 and sunspot number R. We apply linear fitting method.

$$foF2 = D_{0\,h,m} + D_{1\,h,m.} * R \qquad (2)$$

Where, h and m are hour and month. D_0 and D_1 are constants; R is the twelve-month running mean value of sun spot numbers. D_0 and D_1 are calculated by curve fitting method.

The Second Degree Regression is expected to make improvement & the quadratic relationship between sunspot number R & foF2 is described as:

$$foF2_{h,m} = E_{0h,m} + E_{1h,m}*R + E_{2h,m}*R^2 \qquad (3)$$

Where E_0, E_1 & E_2 are the coefficients at specified time h & month m.

III Result

Figure 1 represents the diurnal variation of foF2 for month January 2014, which is the high solar activity period of 24th solar cycle. January repents the month of winter. Fourier expansion method is applied to show the diurnal variation. In this graph solid line indicates the model and dotted line shows the observed value. It is seen from figure after sunset the lines are nearly overlapped but at the time of sun rise to sun peak rise model foF2 is just above.

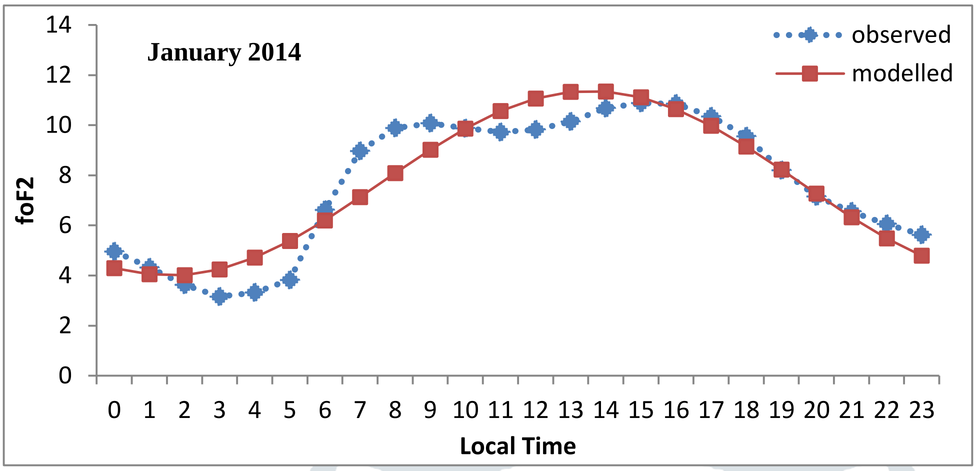

Figure 1
Modelled and observed value plot of foF2 during high solar active period of 24th solar cycle at low latitude station Jicamarca January month is considered as winter season month.

Figure 2 represents the diurnal variation of foF2 for month January 2002, which is the high solar activity period of 23rd solar cycle. January repents the month of winter.

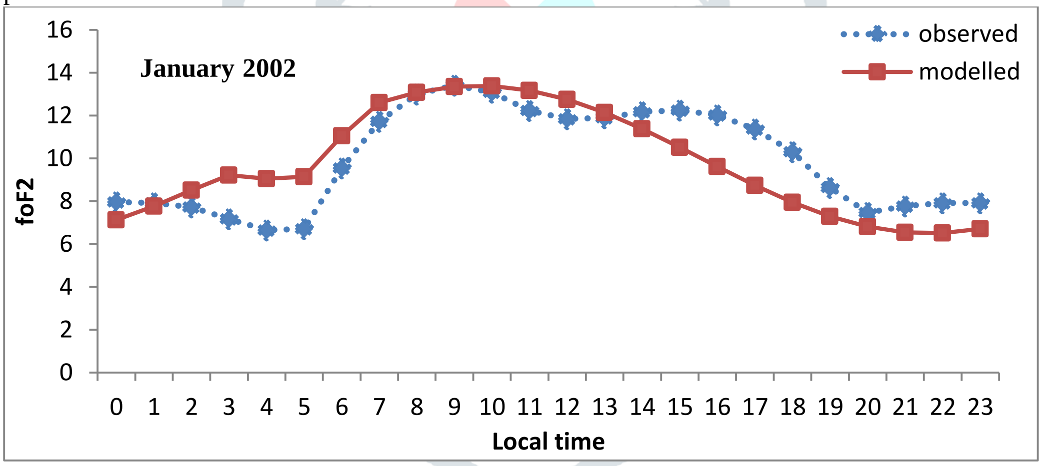

Figure 2
Modelled and observed value plot of foF2 during high solar active period of 23rd solar cycle at low latitude station Jicamarca January month is considered as winter season month.

Figure 3 repents model and observed value plot of foF2 during high solar active period of 24th solar cycle at low latitude station Jicamarca June month is considered as summer season month. After sun set Model and observed value of foF2 are very close. But error is seen in model and observed value during the 4: LT to 14: LT.

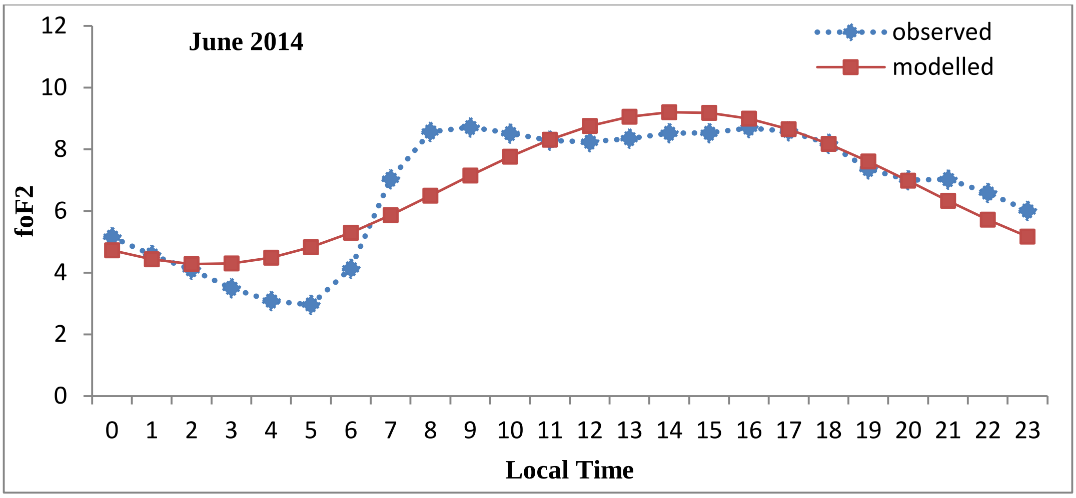

Figure 3

Modelled and observed value plot of foF2 during high solar active period of 24th solar cycle at low latitude station Jicamarca June month is considered as summer season month.

Figure 4 represents the model and observed value plot of foF2 during high solar active period of 23rd solar cycle at low latitude station Jicamarca June month is considered as summer season month.

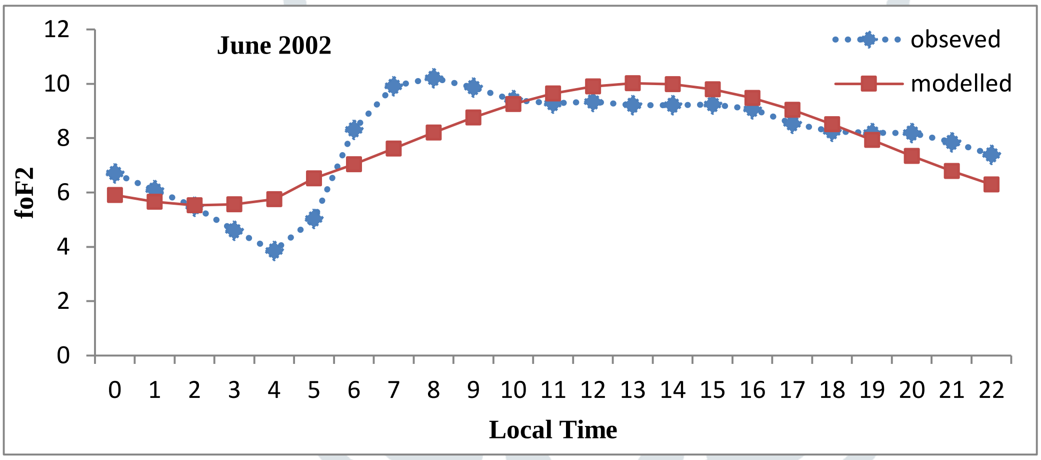

Figure 4

Modelled and observed value plot of foF2 during high solar active period of 23rd solar cycle at low latitude station Jicamarca June month is considered as summer season month.

Figure 5 represents model and observed value plot of foF2 during high solar active period of 24th solar cycle at low latitude station Jicamarca September month is considered as equinox season month.

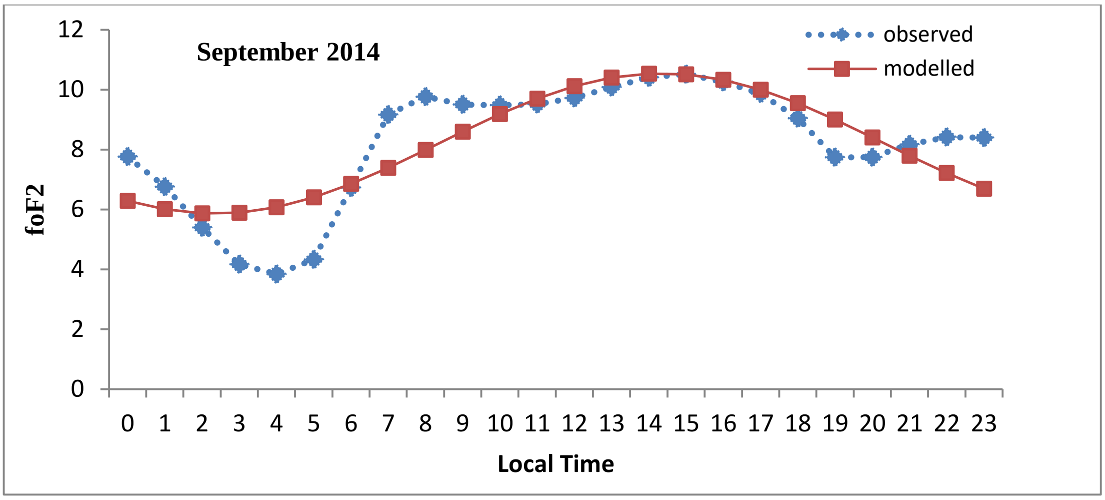

Figure 5
Modelled and observed value plot of foF2 during high solar active period of 24th solar cycle at low latitude station Jicamarca september month is considered as equinox season month.

Figure 6 represents the model and observed value plot of foF2 during high solar active period of 23rd solar cycle at low latitude station Jicamarca, September month is considered as equinox season month.

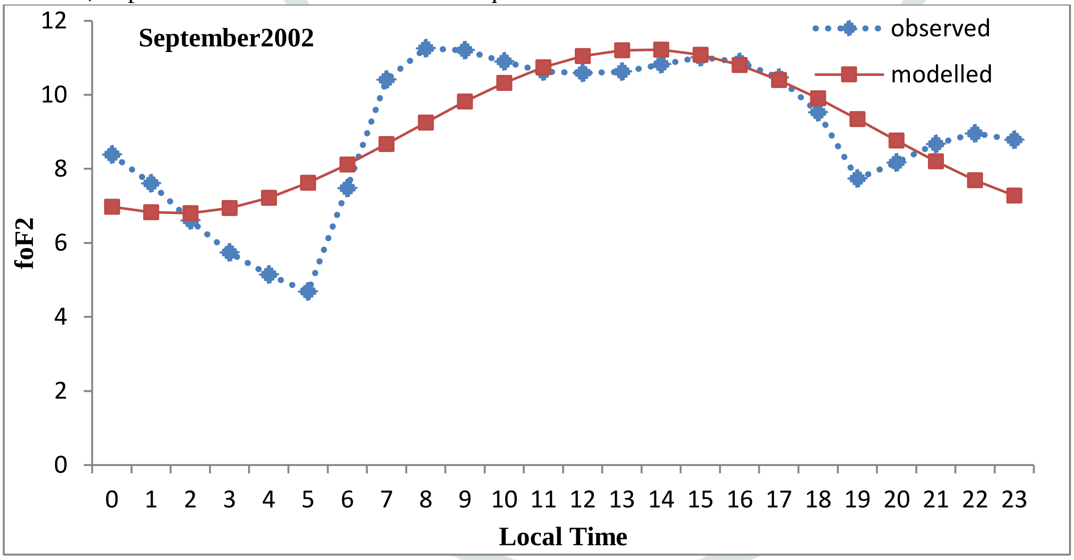

Figure 6
Modelled and observed value plot of foF2 during high solar active period of 23rd solar cycle at low latitude station Jicamarca September month is considered as equinox season month.

Figure 7 represents sample fit result relation between sun spot numbers R and foF2 to show solar activity dependent. Modelled value represented by solid line while dash line shows observed value of high solar activity of 24th solar cycle.

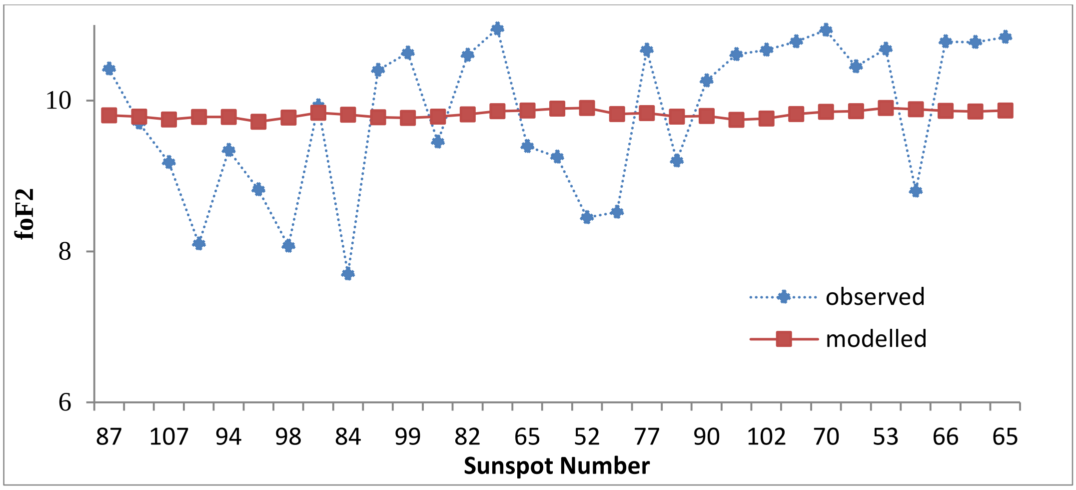

Figure 7
Relation between sun spot numbers R and foF2 to show solar activity dependent of foF2 during high solar activity of 24th solar cycle

Figure 8 represents relation between sun spot numbers R and foF2 to show solar activity dependent by the Second Degree Regression Method. Model value is represented by solid line while dash line shows observed value of high solar activity of 24th solar cycle.

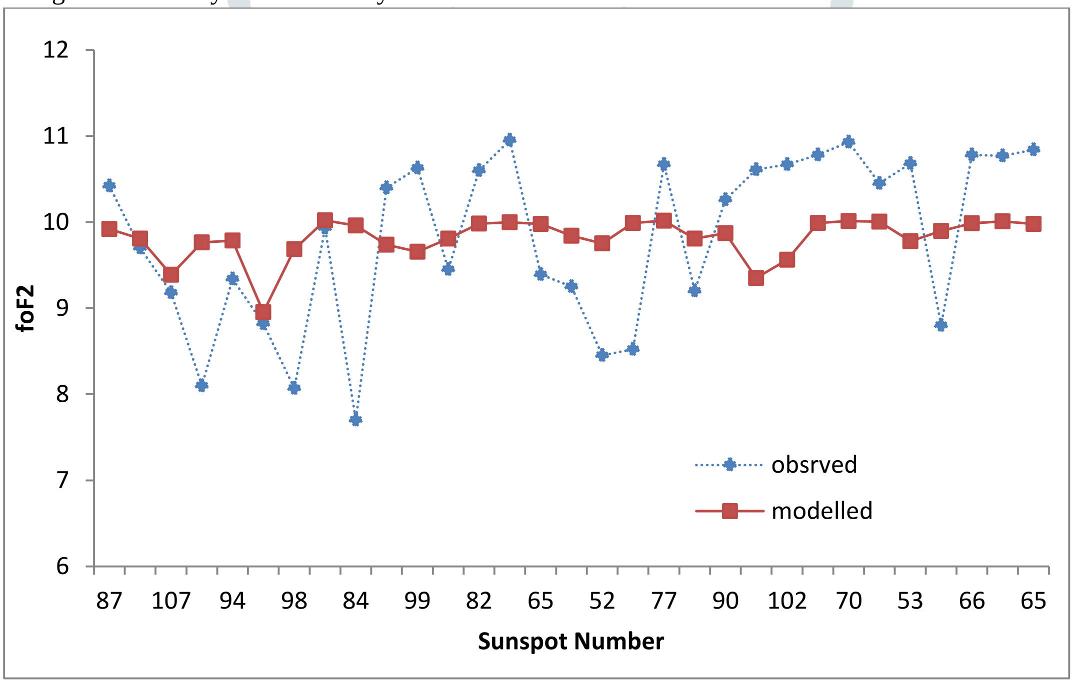

Figure 8
Relation between sun spot numbers R and foF2 to show solar activity dependent Modelled value represented by solid line while dash line shows observed value of high solar activity of 24th solar cycle
(By the Second Degree Regression Method)

IV Discussion

Global models may spread out features unique to a particular region; single-station models are widely useful and viewed as the milestone for ionospheric services. We know that ionosphere electron density is mainly occurs due to neutral atmosphere ionization by solar radiation, hence electron density of F-region increases with the increasing of solar activity, where in case of monthly median foF2, foF2 increases with solar activity is complicated. It saturates at extremely high solar epochs.

Fourier expansion method is applied to show the diurnal variation. In this graph solid line indicates the model and dotted line shows the observed value. It is seen from figure after sunset the lines are nearly overlapped but at the time of sun rise to sun peak rise model foF2 is just above observed value. The present model can possibly improved further during the sun rising period there are some other factors that affect the ionization at that time period. It is the attempt to show the diurnal variation by Fourier's harmonic analysis method for high solar activity period of 23rd and 24th solar cycle.

Sethi et al. (2002) investigate the longitudinal dependence of solar cycle variation of foF2 is almost entirely dependent on nonlinear solar activity. Furthermore, at noon in each month, $b_2<0$, i.e. when sunspot number R reaches high enough, the monthly median foF2 decreases with the increasing solar activity. But at midnight in winter, $b_2>0$, indicating that foF2 increases with the increasing of solar activity, i.e. the saturation effect is barely visible.

Liu Libo (2012) has given Ionospheric sounding operated at Wuhan Ionospheric (WIO) Observatory ($114.4E^0$ $30.6N^0$) has a history over 60 years, so WIO has the longest routine ionospheric observations. A series of single station models have been constructed on the basis of WIO observations.

Liu et al (2009) constructed models of foF2 using Fourier expansion and cubic-B splines approaches. The foF2 models have good prediction accuracies with standard deviations in about 0.26 to 0.58MHz.

Our model is good agreement with observed value of foF2.

V Conclusion

The presented model is based on furrier series expansion higher harmonics are also considered for improvement. Our results are matched at the time of sunset periods. When the sun rises and ionization increases then model and observed value do not exact match. We also focused solar activity relation between foF2 and sunspot number, nonlinear dependent is observed.

VI Acknowledgement

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