Volume : 3 | Issue : 4 | April 2014 • ISSN No 2277 - 8160

Research Paper | Astronomy

Ionospheric Empirical Mathematical Formula to Forecast the Critical Frequency of F2-layer over Athen

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ABSTRACT

In the present work, the variation of the ionospheric critical frequency of the F2-layer (foF2) has been studied over Athens city. The real-time digisonde dataset of the national observatory of Athens which is represented one of the most advanced European real-time ionospheric stations has been analysised for the monthly period of the years (2011, 2012, 2013). An analytical investigation has been conducted for the 12 months of the studied years. Depending on the results of this study, the correlation relationship between the monthly median values of foF2 and hourly time factor have been expressed as an empirical mathematical formula which represented by a forth order polynomial regression. The predicted values that were generated from the suggested formula and IRI model gave a good fitting with the observational digisonde data for all years. Also, the correlation coefficient (R2) values that were obtained from studying the correlation between the predict values and the observed data presented a very good correlation between each other. As a result of this study, the suggested mathematical formula can predicted a more accurate, simple, and reliable values than that calculated using other theoretical models.

KEYWORDS: critical frequency, HF communication, ionospheric characteristics, digisonde, ionospheric model

Introduction

It is well known the solar activity is the main source that has very strong influence on the upper part of the Earth's atmosphere, some of existed natural atoms in this region become excited when the solar radiation is reached and this leads to stripping the electrons from the atoms resulting ionization region called the ionosphere [1]. It consists of four distinct layers according to the abundance of the excited electrons and the height, namely D, E, F and topside. The F layer is divided into F1and F2 layers [2]. The F2 layer is playing a unique role to propagate HF radio communication for long and short distances in the frequency range (2-30) MHz due to its highest electron densities and to determine many parameters like critical frequency (f_oF2), propagation factor M(3000), peck height of the F2 layer (h_mF2) and others [3]. The f_oF2 is an important parameter for describing the state of ionospheric variation and defined as the highest frequency signal that will reflect directly back to its transmission location depending on the time of day and day of the sunspot cycle. It is related to the maximum electron density of F2 layer (N_mF2) according to the following equation [4]:-

$$(f_oF2)^2 = \frac{N_mF2e^2}{4\varepsilon_o m\pi}$$

Where

f_oF2 = critical frequency of the F2 layer.

N_mF2 = max. electron density of the F2 layer

e = electron charge.

ε_o = vacuum permittivity.

m = mass of electron.

As a prelude to the theoretical studies of ionospheric variability that have pursued in the 1970's the daily variations of the ionosphere is dominated by the geomagnetic storm [5]. The hourly critical frequencies f_oE, f_oF1, and f_oF2 for mid latitudes have been examined to predict radio propagation conditions for short time [7].

In early 1980's, the sounding sites in mid latitudes showed that critical frequency of F2 layer that represents the maximum electron density of this plasma is affective to solar activities. The relationship between f_oF2 and solar activity during the minimum and peak of the solar cycle has been investigated for long term [8]. Also, in the same time the seasonal and solar cycle variations of the ionospheric characteristics were studied for specific local time [9].

In the last years, studies showed that the pattern of ionospheric behavior is highly varied with geographical location, distance and orientation. The variation of geophysical characteristics of f_oF2 at certain latitude for universal time is sensitive to the diurnal variation of the instantaneous mean-longitudinal [9]. The physical characteristics of the ionospheric variation have been investigated for different stations with the same latitudes during a diurnal time in order to study the regular variations of the ionosphere in quiet conditions [10].

Various regional and empirical models of forecasting f_oF2 which are based on statistical analyses of long-term records of ionospheric observations have been suggested by many researchers, for example, Balan N (1994) [11], Sole, J. G (1998) [12], T. D. Xenos (2002) [13], Lei J (2005) [14], Xu T (2008) [15], H. Chandra (2009) [16], T.L. Gulyaeva (2010) [17], Brum C G M (2012) [18], [19] (2012) [20], Karima Benghanem (2013) [21].

International Reference Ionosphere

Over many years, numerous global organizations and unions, like (Committee Consultative International des Radio Communications (CCIR), International Telecommunication Union (ITU)) have developed many models in order to estimate the monthly median ionospheric characteristics of the F2 layer, like, (f_oF2), and (M(3000)F2), … etc [22]. Also, other long term prediction models like, "NeQuick, Di Giovanni and Radicella (DGR) models" are created to predict the ionospheric char-

acteristics in the HF radio rang (2-30) MHz that routinely scaled from ionograms [23].

As recent studies, the International Reference Ionosphere (IRI) was appeared to predict f_oF2 by a numerical map which was developed by CCIR [24]. Also, in the late sixties several versions of the IRI model have been developed by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). These organizations formed a Working Group and have been released in hard copy as well as in computer-readable form [25].

The IRI-78 (computer program: Version No. 5) model was the first widely issued edition which is described in a red booklet, issues (1&2). As far away from the past many updates for IRI-78 have been achieved by checking the validating of it with the observed data of ground and space stations [26].

At the end of 1980, a new computer program of IRI-80 model (Version No.7) was released in issue /3/ of the yellow reports of the World Data Center (WDC) for Solar-Terrestrial Physics [27]. After six consecutive years, the IRI-86 model (Version No. 9) was the first edition appeared as available online through global networks and also for use on personal computers. It is represented a better program for the equatorial topside electron density profile and electron temperature [28].

Over a period of time, a modern Version IRI-90 was presented as a green book of issue /4/ in the report series of the National Space Science Data Center and World Data Center A for Rockets and Satellites (NSSDC/WDC-A-R&S) and was distinguished by several new input options for the electron density and ion composition [29].

In the 1995, an online version of IRI-95has been improved for low magnetic latitudes in order to predict ionospheric densities and temperatures exhibit characteristic variations in and near the oval region and, therefore, the inclusion of an oval description in IRI has long been a high priority of the IRI team [31]. Also many modifications for IRI model have been made during year 2001 to predict new parameters like Fl probability, equatorial vertical ion drift [31] [32]. After long time, the newest version of IRI-2007 model has been released by introduced two options. The first is a correction factor for the 2001 model which based on topside profiles [33] and the second is the NeQuick topside model that was developed by S. Radicella and his collaborators over the last decade [34].

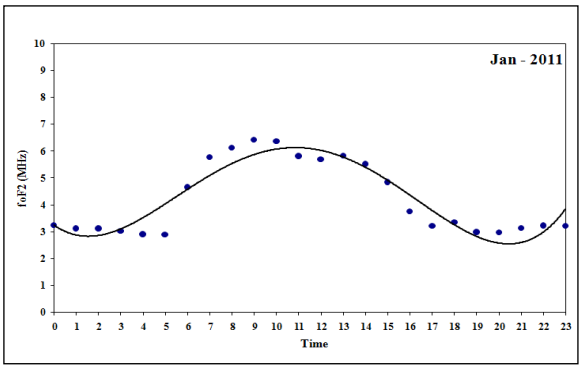
Currently, the last version of IRI-2012 model has been issued which was included significant improvements not only for the representation of electron density, but also for describing the electron temperature, ion temperature and ion composition in the altitude range from 50 km to 2000 km in addition to f_oF2, f_oF1, f_oE, M(3000) and others for a given location, time and date.

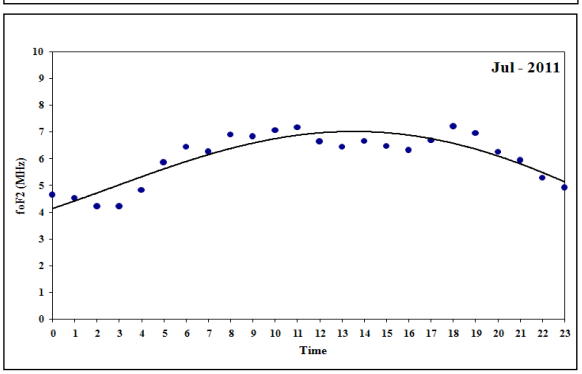
Test and Results

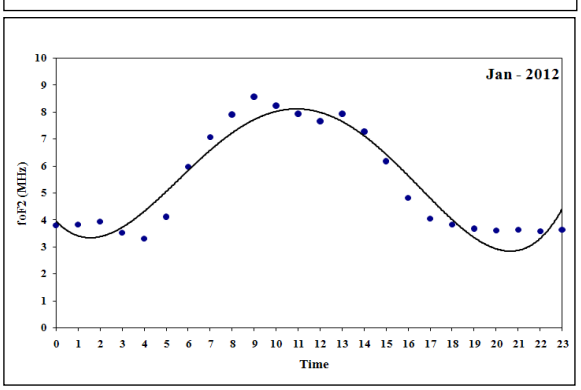
The aim of this research is constructing a simplified empirical model of the f_oF2 parameter over Athen city. The Digital Ionogram Data Base (DIDBase) measurements of a single digisonde Portable Sounder-4 (DPS-4) station that is laid on the geographical longitude (23.5 E) and latitude (38 N) have been collected for the daily 24 UT hours of the years (2011, 2012 and 2013).

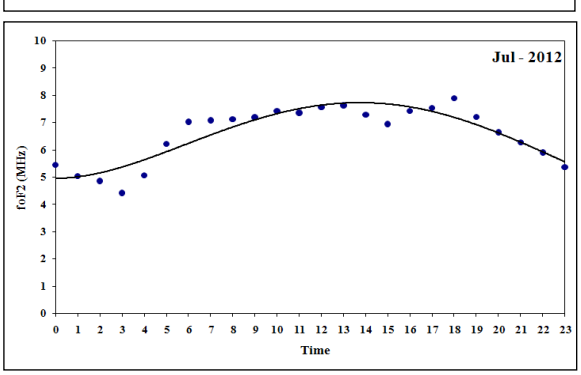
The IRI- 2012 model, which represents one of the famous forecasting international models of the ionospheric assessment studies has been adopted to calculate the ionospheric characteristics for the selected years over Athens zone. The topside electron concentration profile technique "NeQuick" of the IRI-2012 model has been selected to estimate the f_oF2 parameter, because it gave a more accurate, fast, and reliable ionospheric characteristics results beside it's a more suitable technique that used to study the trans-ionospheric radio propagation characteristics.

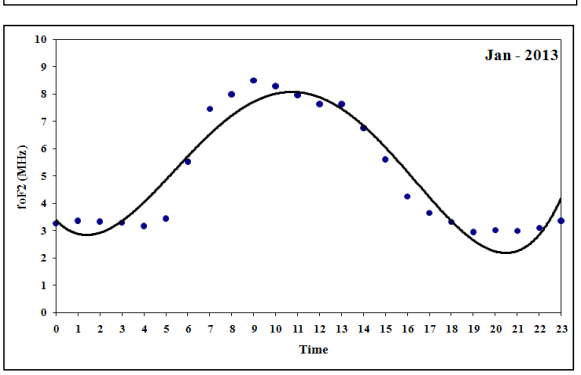
The statistical analysis of the gathered f_oF2 datasets that obtained from the digisonde station has been achieved for the diurnal 24 hours and monthly periods of the adopted years. Figure (1) shows samples of the scatter plots of the analytical study of f_oF2 for the years 2011, 2012, 2013.











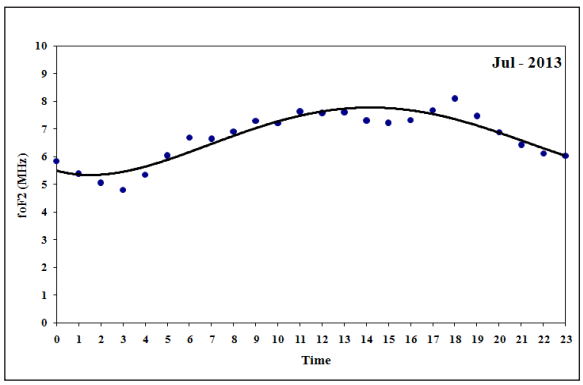


Figure 1 scatter plots of the analytical investigation between f_oF2 values and time for years (2011, 2012, 2013).

Depending on the results of the analytical investigation that have conducted for the 12 months of the picked years. The correlation relationship between the monthly median values of f_oF2 and hourly time factor has been expressed by a forth order polynomial regression which represented by the following equation:-

$$f_oF2 = a_o + a_1x + a_2x^2 + a_3x^3 + a_4x^4$$

Where

a_o, a_1, a_2, a_3, a_4 : are polynomial coefficients.

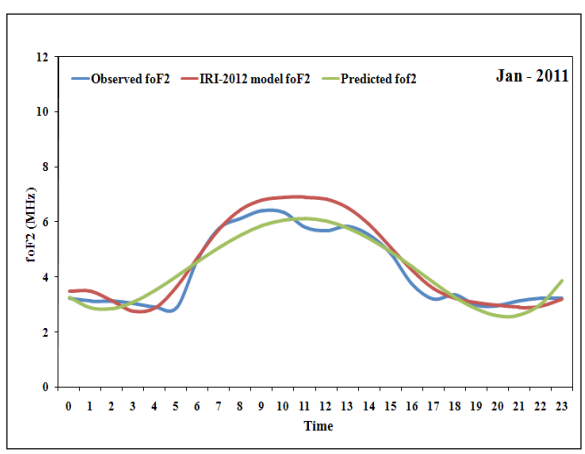
x : is the time parameter.

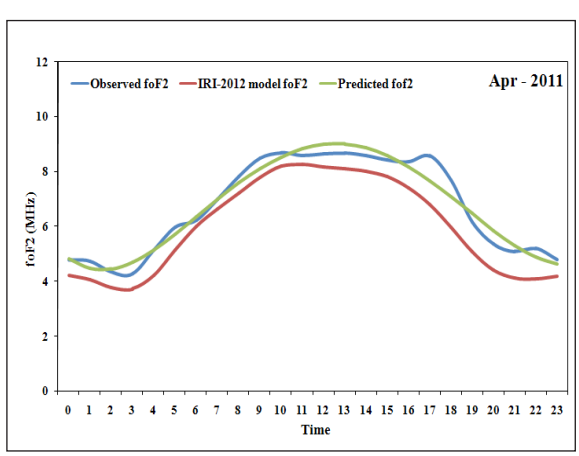
Table (1) presents the values of the polynomial coefficients (a_o, a_1, a_2, a_3, a_4) and the correlation coefficient (R^2) that generated from correlation study between the monthly median values of f_oF2 and hourly time for the years 2011, 2012 2013.

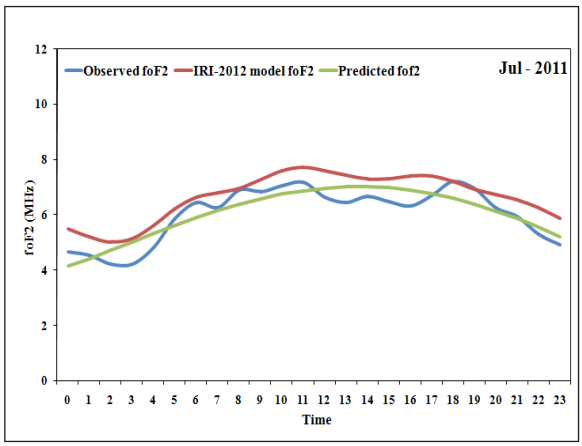
Table 1 the correlation coefficients values (a_{go}, a_1, a_2, a_3, a_4) and correlation coefficients (R^2) for the tested years.

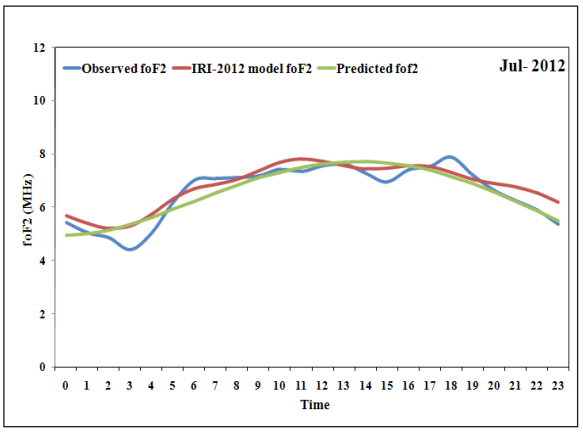
2011						
Month	a_o	a_1	a_2	a_3	a_4	R^2
Jan	3.251	- 0.595	0.234	-0.019	0.0004	0.882
Feb	3.478	- 0.685	0.266	- 0.021	0.0005	0.957
Mar	3.988	- 0.92	0.332	- 0.025	0.0006	0.96
Apr	4.809	- 0.555	0.217	- 0.016	0.0003	0.96
May	5.068	- 0.024	0.065	- 0.005	0.0001	0.922
Jun	5.019	- 0.063	0.075	- 0.006	0.0001	0.866
July	3.251	- 0.595	0.234	-0.019	0.0004	0.882
Aug	3.815	- 0.34	0.014	- 0.002	0.00003	0.848
Sep	4.31	- 0.31	0.176	- 0.013	0.0003	0.937
Oct	4.192	- 0.994	0.416	- 0.033	0.0007	0.966
Nov	3.781	- 0.603	0.344	- 0.029	0.0007	0.952
Dec	3.873	- 0.623	0.303	- 0.025	0.0006	0.926
2012						
Month	a_o	a_1	a_2	a_3	a_4	R^2
Jan	3.93	- 0.838	0.331	-0.027	0.0006	0.915
Feb	3.781	- 0.626	0.298	- 0.024	0.0005	0.928
Mar	4.469	- 0.894	0.34	- 0.026	0.0006	0.985
Apr	4.946	- 0.802	0.284	- 0.021	0.0004	0.977
May	5.889	- 0.53	0.185	- 0.013	0.0003	0.966
Jun	-	-	-	-	-	-
July	4.942	- 0.003	0.058	-0.004	0.0001	0.835
Aug	4.352	- 0.101	0.1	- 0.007	0.0001	0.927
Sep	4.343	- 0.355	0.207	- 0.016	0.0003	0.94
Oct	4.496	- 0.894	0.34	- 0.026	0.0006	0.985
Nov	3.824	- 0.952	0.395	- 0.032	0.0007	0.927
Dec	3.453	- 0.763	0.308	- 0.025	0.0006	0.879
2013						
Month	a_o	a_1	a_2	a_3	a_4	R^2
Jan	3.381	- 0.824	0.353	- 0.029	0.001	0.916
Feb	3.633	- 0.703	0.307	- 0.025	0.001	0.957
Mar	4.143	- 0.802	0.32	- 0.024	0.001	0.973
Apr	4.990	- 0.529	0.233	- 0.017	0.0003	0.979
May	5.551	- 0.153	0.117	- 0.008	0.0002	0.96
Jun	5.249	- 0.089	0.078	- 0.008	0.0002	0.914
July	5.483	- 0.221	0.085	-0.005	0.0001	0.868
Aug	4.941	- 0.215	0.107	- 0.007	0.0001	0.937
Sep	4.432	- 0.906	0.329	- 0.024	0.0005	0.939
Oct	4.222	- 0.984	0.401	- 0.031	0.0007	0.973
Nov	3.874	- 0.92	0.416	- 0.034	0.0008	0.94
Dec	3.688	- 0.98	0.396	- 0.032	0.0007	0.925

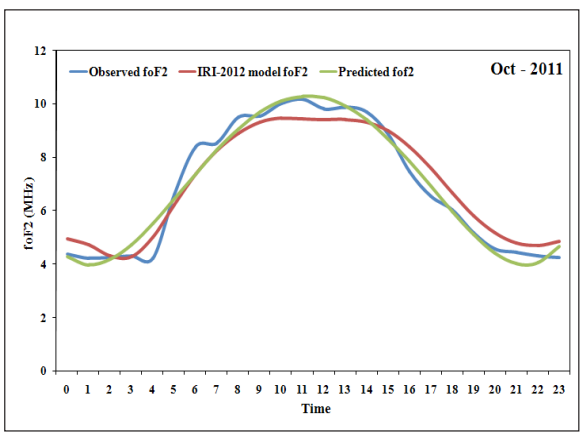
The predicted values of f_oF2 that have been generated using the suggested mathematical formula are illustrated in figure (2). figure (2) show samples of the monthly predicted f_oF2 values "using a suggested formula" compared with the observed data and the values that calculated from executing the IRI model of the studied region for the years (2011, 2012, 2013).

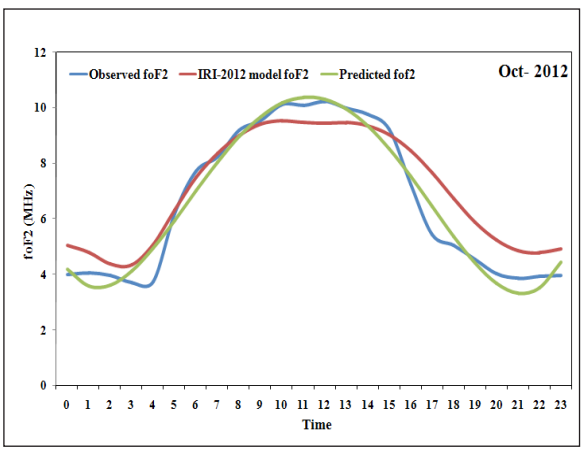


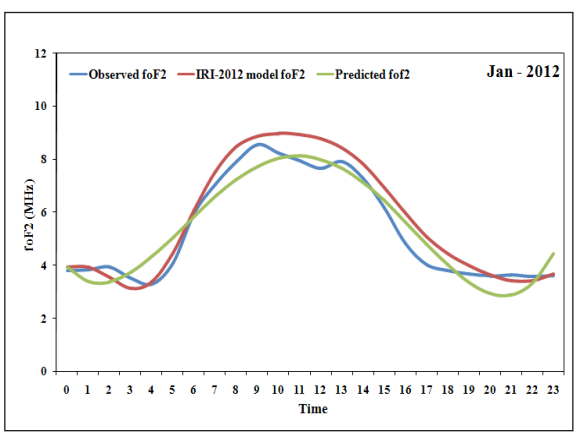


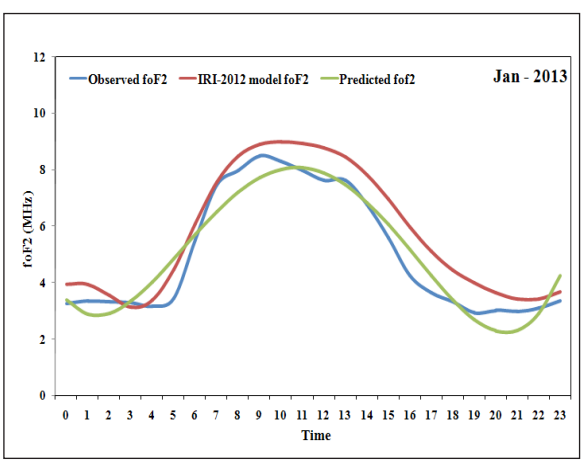

Observed foF2
IRI-2012 model foF2
Predicted fof2
Jul - 2011
foF2 (MHz)
Time

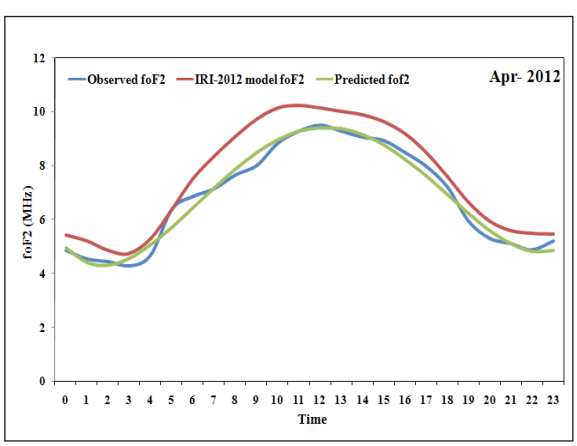

Observed foF2
IRI-2012 model foF2
Predicted fof2
Jul- 2012
foF2 (MHz)
Time

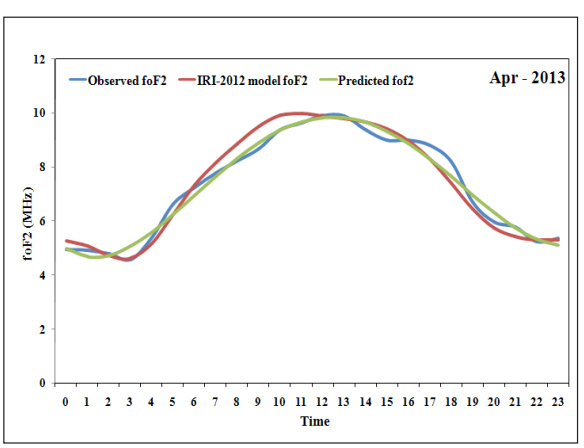

Observed foF2
IRI-2012 model foF2
Predicted fof2
Oct - 2011
foF2 (MHz)
Time

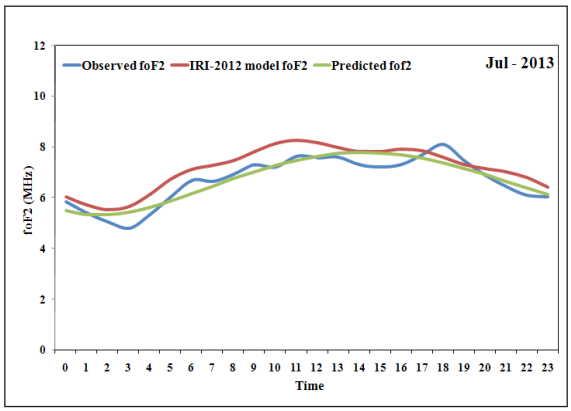

Observed foF2
IRI-2012 model foF2
Predicted fof2
Oct- 2012
foF2 (MHz)
Time


Observed foF2
IRI-2012 model foF2
Predicted fof2
Jan - 2012
foF2 (MHz)
Time


Observed foF2
IRI-2012 model foF2
Predicted fof2
Jan - 2013
foF2 (MHz)
Time


Observed foF2
IRI-2012 model foF2
Predicted fof2
Apr- 2012
foF2 (MHz)
Time


Observed foF2
IRI-2012 model foF2
Predicted fof2
Apr - 2013
foF2 (MHz)
Time



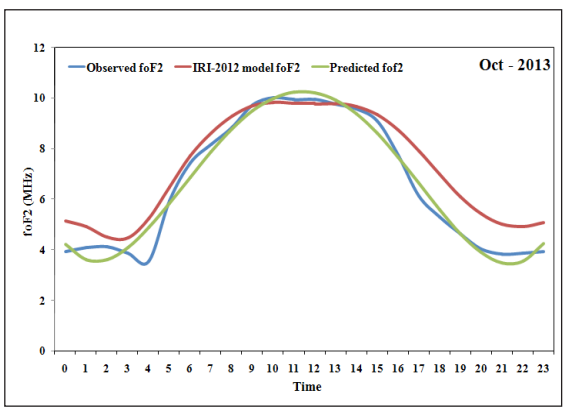
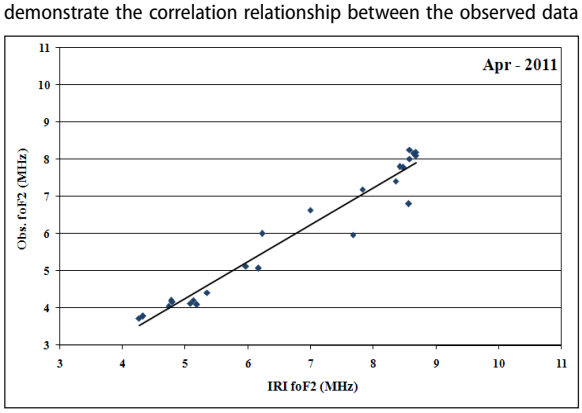
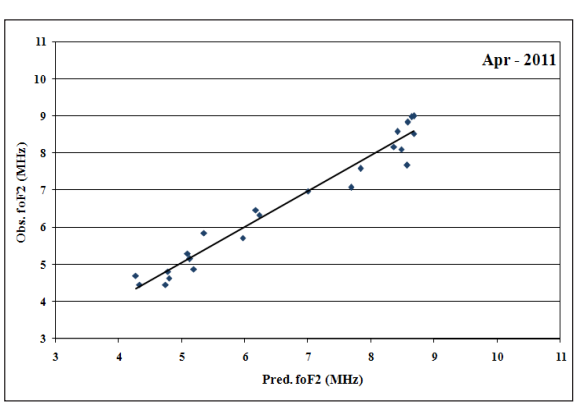
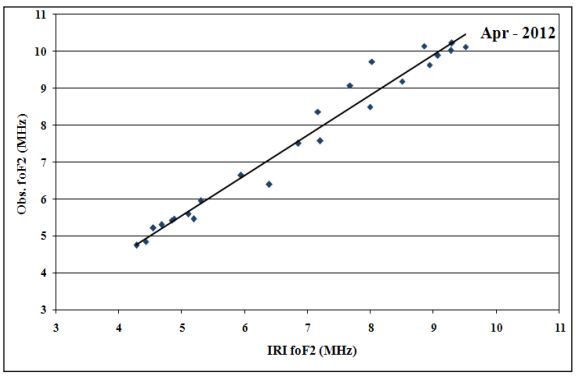


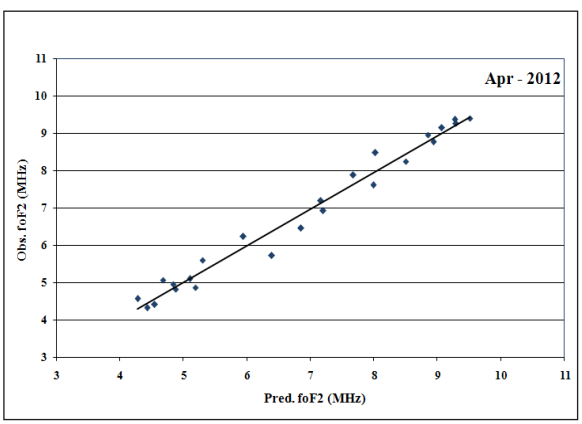
Figure 2 samples of comparison among the empirical and IRI models results and digisonde dataset for selected years.

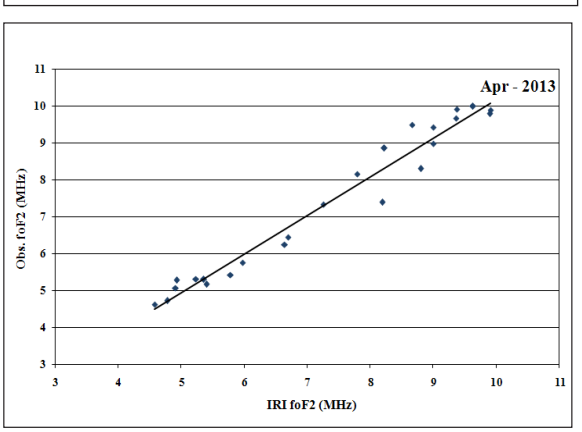
To verify the accuracy of the empirical mathematical equation, the correlation between the predicted f_oF2 values of the suggested formula and the IRI model with the observed results that obtained from the digisonde station have been investigated. Figure (3) show samples that demonstrate the correlation relationship between the observed data











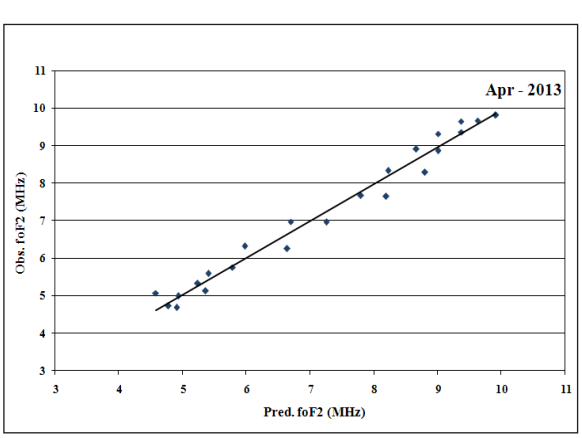


Figure 3 samples shows the correlation relationship between the observed data and the predicted values of the suggested and IRI models

Table (2) shows the correlation coefficient (R^2) values that showed the correlation relationship between the observed, IRI model and suggested formula values of f_oF2.

Table 2 Sample of R-square values of correlation test for years (2011, 2012, 2013)

	Observed f_oF2 (2011)	Observed f_oF2 (2012)	Observed f_oF2 (2013)
IRI Model	0.952	0.973	0.965
Suggested Formula	0.959	0.977	0.979

According to the results of the correlation factors, it can be seen that the predicted f_oF2 values generated from the suggested empirical formula shows better correlation with the observed data than f_oF2 values of IRI model. Also, the correlation coefficient (R^2) results that illustrated in table (2) show better correlation between the predicted and observed f_oF2 than IRI f_oF2 values.

Discussion and Conclusion

Digital ionogram dataset of f_oF2 that have derived from European Athens station has been analysised for monthly time of the years (2011, 2012, 2013).

The monthly correlation exam presented in figure (1), showed that the mathematical relationship between f_oF2 value and the time parameter is simple and can be presented by a forth order polynomial equation.

The investigation of validation and accuracy of the suggested mathematical formula has been performed through the analytical and comparison studies. The results of these studies showed a good agreement between the behavior of the predicted data and the IRI model with the behavior of the observational datasets that obtained form digsonde

REFERENCES

1. S. O. Ikubanni & J. O. Adeniyi, On the Dependence of F2 layer critical frequency on F10.7 solar Flux at an equatorial station, World J of Engineering and Pure and Applied Sci., vol. 2, no. 3, pp. 85-91, 2012. | 2. O. Şahin, U. Sezen, F. Arikan & O. Arikan, Optimization of F2 layer parameters using IRI-plas and IONOLAB-TEC, General Assembly and Scientific Symposium, XXXth URSI, IEEE Xplore, 1-4, 2011. | 3. N. K. Sethi, M. K. Goel & K. K. Mahajan, Solar cycle variations of foF2 from IGY to 1990, Annales Geophysicae, vol. 20, no. 10, pp. 1677-1685, 2002. | 4. Z. Mošna, P. Šauli & O. Santolík, Analysis of Critical Frequencies in the Ionosphere, WDS'08 Proceedings of Contributed Papers, Part II, pp. 172-177, 2008. | 5. M. Mendillo, K. Schatten, Influence of solar sector boundaries on ionospheric variability, Journal of Geophysical Research, vol. 88, pp. 9145-9153, 1983. | 6. C.M. Rush & J. Gibbs, Predicting the day-to-day variability of the mid-latitude ionosphere for application to HF propagation predictions. AFCRL-TR-73-0335, Air Force Geophysics Laboratory, Hanscom AFB, MA, USA, 1973. | 7. O.M. Barkhatova, A.E. Levitin, I.A. Dodonova & N.V. Kosolapova, Classification of ionospheric disturbances at middle latitudes based on long term observation, Physics of Auroral Phenomena, Proc. XXXIV Annual Seminar, Apatity, pp. 125-128, 2011 | 8. A. S. Besprosvanaya & P. E. Kozina, Variations of the electron density in the F2-layer maximum in the solar activity cycle, Geomagn. Aeron., vol. 28, 639-643, 1988. | 9. V. V. Kuznetsov, V. V. Plotkin, I. I. Nesterova & M. S. Pozdeeva, Universal diurnal variation of F2-layer critical frequency, J. Geomag. Geoelectr., vol. 42, pp. 1237-1240, 1990. | 10. V. V. Kuznetsov, V. V. Plotkin, G. V. Nesterova & I. I. Nesterova, Universal variation of the F2-layer critical frequency and solar activity, Earth Planets Space, vol. 50, pp. 57-61, 1998. | 11. N. Balan, G. J. Bailey & B. Jenkins, Variations of ionospheric ionization and related solar fluxes during an intense solar cycle. J Geophys Res, vol. 99, doi: 10.1029/93JA02099, 1994. | 12. J. G. Sole, Relations between hourly monthly median values of foF2 and some geophysical indices. Their application to an ionospheric single station model, Acta Geophys. Polonica, XLVI, pp. 77-88, 1998. | 13. T. D. Xenos, Neural-network-based prediction techniques for single station modeling and regional mapping of the foF2 and M(3000)F2 ionospheric characteristics, Nonlin. Processes Geophys.,vol. 9, pp. 477-486, 2002. | 14. J. Lei, L. Liu & W. Wan, Variations of electron density based on long-term incoherent scatter radar and ionosonde measurements over Millstone Hill. Radio Sci, vol. 40, no. 2, DOI: 10.1029/2004RS003106, 2005. | 15. T. Xu, Z. S. Wu & J. Wu, A single-station spectral model of the monthly median foF2 over Chongqing, China. Ann Geophys, vol. 51, pp. 609-618, 2008. | 16. H.Chandra, Som Sharma & Soe Win Aung, Day to day variability in the critical frequency of F2 layer over the anomaly crest region, Ahmedabad, J. nd. Geophys. Union, vol.13, no.4, pp.217-226, 2009. | 17. T.L. Gulyaeva, Storm time behavior of topside scale height inferred from the ionosphere-plasmasphere model driven by the F2 layer peak and GPS-TEC observations, Adv. Space Rec., vol. 47, no. 6 pp.913-920, 2011. | 18. C. G. M. Brum, F. S. Rodrigues & P. T. dos Santos, A modeling study of foF2 and hmF2 parameters measured by the Arecibo incoherent scatter radar and comparison with IRI model predictions for solar cycles 21, 22, and 23, J Geophys Res, vol. 116, doi: 10.1029/2010JA015727, 2011. | 19. O. R. Salami & E.F. Nymphas, Variability of critical frequency of F2 layer foF2, in west Africa using ionosonde stations at Ouagadougou and Dakar, Research Journal of Applied Sciences, vol. 7, no. 9-12, pp. 474-480, 2012. | 20. K. Benghanem, M. Idres & S. Kahlouche, Detection of ionospheric foF2 variations before strong earthquakes, EGU General Assembly, Vienna, Austria, 2013. | 21. W. B. Jones & R. M. Gallet, Representation of diurnal and geographical variation of ionospheric data by numerical methods, Telecommun. J., vol. 29, pp. 129–149, 1962. | 22. P. Bradley, PRIME (Prediction and Retrospective Ionospheric Modelling over Europe), Cost Action 238, Final Report, Rutherford Appleton Laboratory, Chilton Didcot, UK, 1999. | 23. P. Coïsson, S. Maria Radicella & B. Nava, Comparisons of experimental topside electron concentration profiles with IRI and NeQuick models, Annals of Geophysics, vol. 45, no. 1, pp. 111-116, 2002. | 24. D. Bilitza, K. Rawer, L. Bossy and T. Gulyaevat, International refrerence ionosphere-past present and future : I. electron density, , Adv. Space Rec., vol. 13, no. 3, pp. 3-13, 1993. | 25. K. Rawer, S. Ramakrishnan & D. Bilitza, International Reference Ionosphere 1978, International Union of Radio Sci., URSI Special Report, pp. 75, Bruxelles, Belgium, 1978. | 26. K. Rawer, J.V. Lincoln & R. o. Conkright, International Reference Ionosphere-IRI 79, World Data Center A for Solar-Terrestrial Physics, Report UAG-82, pp. 245, Boulder, U.SA, 1981. | 27. D. Bilitza, International reference ionosphere: recent developments, Radio Sci vol. 21, pp. 343–346, 1986. | 28. D. Bilitza, International reference ionosphere 1990, NSSDC/WDC-A-R&S 90-22 National Space Science Data Center, Greenbelt, Maryland, 1990. | 29. Szuszczewicz E P. Wilkinson, W. Swider, S. A. Pulinets, M. A. Abdu, E. Roelof, T. Fuller-Rowell, D. S Evans, T. Bateman & P. Blanchard, Measurements and empirical model comparisons of F-region characteristics and auroral boundaries during the solstial SUNDAIL campaign of 1987. Ann Geophys vol. 11, pp. 601–613, 1993. | 30. D. Bilitza, International reference ionosphere 2000, Radio Sci, vol. 36, no. 2, pp. 261–275, 2001 | 31. B.W. Reinisch & X.Huang, Finding better BO and B1 parameters for the IRI F2- profile function. Adv. Space Res., vol 22, no. 6, pp. 741-747, 1998. | 32. D . Bilitza, X . Huang, B. Reinisch, R. Benson, HK Hills, WB Schar, Topside ionogram scaler with true height algorithm (TOPIST): automated processing of ISIS topside ionograms. Radio Sci, vol. 39, no. RS1S27, doi:10.1029/2002RS002840, 2004. | 33. SM Radicella & R. Leitinger, The evolution of the DGR approach to model electron density profiles. Adv Space Res, vol. 27, no. 1, pp. 35–40, 2001. | 34. D. Bilitza, S. A. Brown , M. Y. Wang & J. R. Souza, P. A. Roddy, Measurements and IRI model predictions during the recent solar minimum, Journal of Atmospheric and Solar-Terrestrial Physics, vol. 86, pp. 99-106, 2012.