

Comparison Ionospheric Critical Frequency ($foF2$) Measurements with IRI-2007 and IRI-2012 Model Predictions at Mid Latitude Station during Low and High Solar Activity

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Abstract

Measurements of the critical frequencies, $foF2$, obtained from ionosonde DPS-4 at a mid latitude station in Rome (geographic coordinates 41.8°N, 12.5°E), Italy, have been compared with the International Reference Ionosphere (IRI-2007), (IRI-2012) models using Comite' Consultatif International Des Radio Communications (CCIR) and Union Radio-Scientific Internationale (URSI) coefficients, during low and high solar activity. The data coverage hourly seasonal values of $foF2$ for low and high solar activity years 2008 and 2012. By comparing the results of IRI models and measured values of $foF2$ at Rome, it was found that (1) generally, the $foF2$ obtained from the (URSI and CCIR Coefficients) for both IRI models are closely follow observed $foF2$ values. (2) In low solar activity year 2008, both IRI-2007 and IRI-2012 (CCIR and URSI Coefficients) give $foF2$ values close to the ones measured at Rome. (3) In high solar activity year 2012, the results of IRI-2012 give $foF2$ values with smaller range of deviation than IRI-2007 results from measured values. The comparative study gives feedback for new improvements of IRI-2012 model.

Keywords: Comparison, Critical Frequencies, Predictions and Solar Activity.

مقارنة قياسات الترددات الحرجة ($foF2$) لمحطة ايونوسفيرية عند خطوط العرض الوسطى مع تنبؤات الموديلات IRI-2007 و IRI-2012 خلال النشاط الشمسي الواطيء والعالي

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الخلاصة

قورنت قياسات الترددات الحرجة لطبقة $F2$ ($foF2$) لجهاز الايونوسوند (DPS-4) في محطة روما (41.8°N, 12.5°E) في ايطاليا، مع تنبؤات موديلات المرجعية العالمية للايونوسفير للعام 2007 (IRI-2007) وللعام 2012 (IRI-2012) بأستخدام المعاملات المعتمدة من قبل اللجنة الاستشارية العالمية للراديو (CCIR) و الاتحاد الدولي لعلوم الراديو (URSI) خلال النشاط الشمسي الواطيء والعالي . تشمل البيانات المستخدمة قيم $foF2$ الساعية الفصلية عند النشاط الشمسي الواطيء في سنة 2008 و عند النشاط الشمسي العالي في سنة 2012. وجد عند مقارنة نتائج موديلات IRI و قيم $foF2$ المقاسة عند محطة روما، ما يلي: (1) بصورة عامة ، تتبع قيم $foF2$ المستخرجة من معاملات CCIR و URSI لموديلي IRI نفس نمط قيم $foF2$ المقاسة من جهاز الايونوسوند . (2) تعطي معاملات CCIR و URSI لموديلي IRI قيم $foF2$ مقاربة الى قيم $foF2$ المقاسة عند النشاط الشمسي الواطيء في سنة 2008. (3) تكون قيم $foF2$ المستخرجة من موديل IRI-2012 بمدى انحراف عن القيم المقاسة اقل من مدى انحرافها من موديل IRI-2007 عند النشاط الشمسي العالي في سنة 2012. دراسة المقارنة اعطت خلفية عن تحسينات جديدة لموديل IRI-2012.

الكلمات المفتاحية : مقارنة، الترددات الحرجة، تنبؤات و النشاط الشمسي.

Introduction

The International Reference Ionosphere (IRI), global empirical model of the ionosphere, is a widely used. IRI is based on experimental measurements of the ionospheric plasma by using space and ground measurements.

IRI describes monthly averages of the critical frequencies of the F_2 -layer in the current ionospheric altitude range of 50–1500 km. IRI predictions are most accurate in Northern mid-latitudes, because of the generally high station density in this part of the globe. Both of these regions have rather sparse ionosonde coverage, partly because of the harsh climate conditions, and as a result the IRI predictions are less accurate at equatorial and auroral latitudes.

One of the most important data sources for the IRI critical frequencies of the F_2 -layer is the worldwide network of ionosonde stations that has monitored the ionosphere with varying station density since the nineteen-thirties. Besides the ionosonde network, other data sources for the model development include the incoherent scatter (IS) radars, several compilations of rocket measurements, and satellite data from in situ and topside sounder instruments. The IS radars measure all of the IRI parameters over the full altitude range, but only a few radars are in operation worldwide. Their data are essential for the description of variations with time, season, and solar activity, whereas the satellite data are a primary source for the description of the global morphology of ionospheric parameters. Two different computer programs have been used as sub-routines by IRI: one is called the Comité Consultatif International Des Radio communications (CCIR Coefficient), which was developed by CCIR committee (CCIR, 1967), (CCIR, 1991) and the other is the Union Radio-Scientifique Internationale (URSI Coefficient), which was developed by

URSI Committee (Rush, *et al.*, 1983), (Rush, *et al.*, 1984), (Rush, *et al.*, 1989), (Fox, *et al.*, 1988).

A large number of papers deal with the comparisons between observed ionospheric data and the IRI model predictions:

The validation of IRI-2007 ionospheric model predictions over the Tehran area during a low solar activity period using data of ionospheric station of the Institute of Geophysics, University of Tehran, have been studied, and it is found that the best agreement occurs during the Summer and Winter, and the largest differences are observed in the Spring and Autumn (Ghader, *et al.*, 2011).

It is found that from comparison of ionospheric F_2 peak parameters foF_2 and hmF_2 with IRI2001 at Hainan, a better agreement between observations and IRI predictions with URSI coefficients in Summer and at low solar activity (Wang, *et al.*, 2009), and the same agreement is founded from comparison of neural network technique with IRI-2001 model ionospheric predictions during great geomagnetic storms for a mid-latitude station (Adewale, *et al.*, 2010). Also at Grahams town, South Africa, it is found from comparison between observed ionospheric foF_2 and IRI-2001 predictions over periods of severe geomagnetic activities, that the model generates good results with observed foF_2 values during geomagnetic storms (Adewale, *et al.*, 2010). Comparative study for foF_2 measurements with IRI-2007 model predictions during extended solar minimum, have been studied, and it is found that IRI provides reliable results that compare well with actual measurements was made (Zakharenkova, *et al.*, 2013).

The purpose of this study is to test the reliability of IRI-2012(the Newest Version of the IRI Model) and the oldest version IRI-2007. In this study, monthly hourly average of foF_2 obtained from IRI-2007 and IRI-

2012(CCIR and URSI Coefficients) during 2008 and 2012 are compared with observed values from mid-latitude station in Rome (Lat. 42° N, Long. 13° E). IRI-2012 is expected to give results more accurate to observed measurements than IRI-2007.

Materials and Methods

The University of Massachusetts Lowell's Center for Atmospheric Research (UMLCAR) has produced digisonde sounders, the Digisonde Portable Sounder(DPS-4), capable of making measurements of the ionosphere and providing real-time on-site processing and analysis to characterize radio signal propagation to support communications or surveillance operations. These DPS-4 distributed in many different regions in the world. Italy interested in monitoring and observing the ionosphere, therefore it has many of ionospheric sounders.

In this paper, measurements of hourly $foF2$ values obtained from Rome (DPS-4) during low and high solar activity years 2008 and 2012 were available in the Space Weather Prediction Center at National Oceanic and Atmospheric Administration (NOAA) at web site: http://www.swpc.noaa.gov/ftpmenu/list/siono_month.html.

The monthly hourly medians of $foF2$ were derived from IRI-2007 (CCIR, URSI) & IRI-2012 (CCIR, URSI) models for years 2008 and 2012 were downloaded from the IRI web sites at: http://omniweb.gsfc.nasa.gov/vitmo/iri_vitmo.html. and http://omniweb.gsfc.nasa.gov/vitmo/iri-2012_vitmo.html. respectively, depending on 12-month smoothed values of the sunspot number (Rz12) which obtained from IPS Radio and Space Services at the web site: <http://www.ips.gov.au/Solar/1/6>. The monthly hourly averages of $foF2$ are derived from hourly $foF2$ data of Rome station and compared with the corresponding ones of IRI models

during low and high solar activity 2008 and 2012.

Statistical analysis was used to calculate standard deviation (SDV) for monthly averages of observed $foF2$ parameter according to equation (1):

$$SDV = \sqrt{\frac{\sum[foF2_{means} - \overline{foF2_{means}}]^2}{(n-1)}} \quad (1)$$

Where $foF2_{means}$ was $foF2$ from measurements, $\overline{foF2_{means}}$ was the average and (n) was the number of data (Kutiev, and Marinov, 2007). The relative difference $\Delta foF2$ (%) is defined as (Bertoni, F., *et al.*, 2006):

$$\Delta foF2(\%) = \left[\frac{(foF2_{IRI} - foF2_{means})}{foF2_{IRI}} \right] * 100 \quad (2)$$

Equation (2) was applied on monthly hourly averages of $foF2$ obtained from IRI-2007 and IRI-2012 models and Rome station measurements, where $foF2_{IRI} = foF2_{CCIR}$ for CCIR coefficient or $foF2_{IRI} = foF2_{URSI}$ for the URSI one.

Results and Discussions

This paper focus on comparison of IRI-2007 and IRI-2012 with ionosonde measurements at mid latitude station during low and high solar activity years 2008 and 2012. Figure (1) showed the monthly sunspot number and its 12-month smoothed number for solar cycle 24 started in January 2008 and expected to reach the peak in May 2013. Figure (1) iwas drawn depending on data obtained from the source (SWPC, 2013). Monthly smoothed sunspot number for years 2008 and 2012 is used as input parameter in IRI models to predict monthly hourly $foF2$ for years 2008 and 2012.

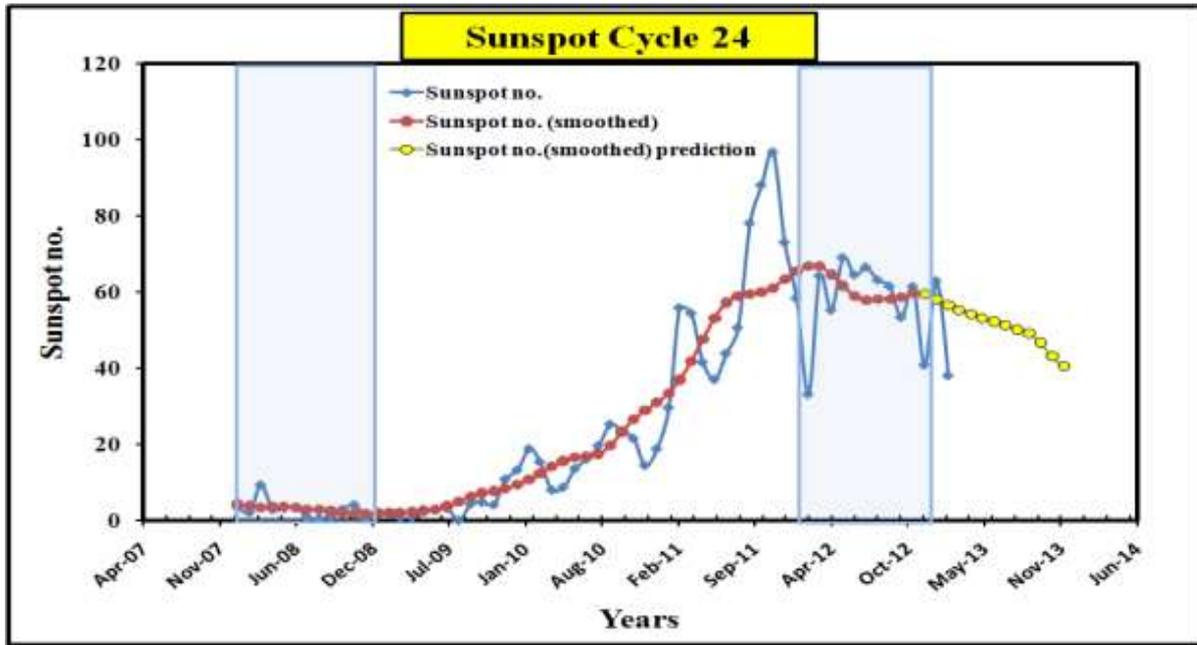
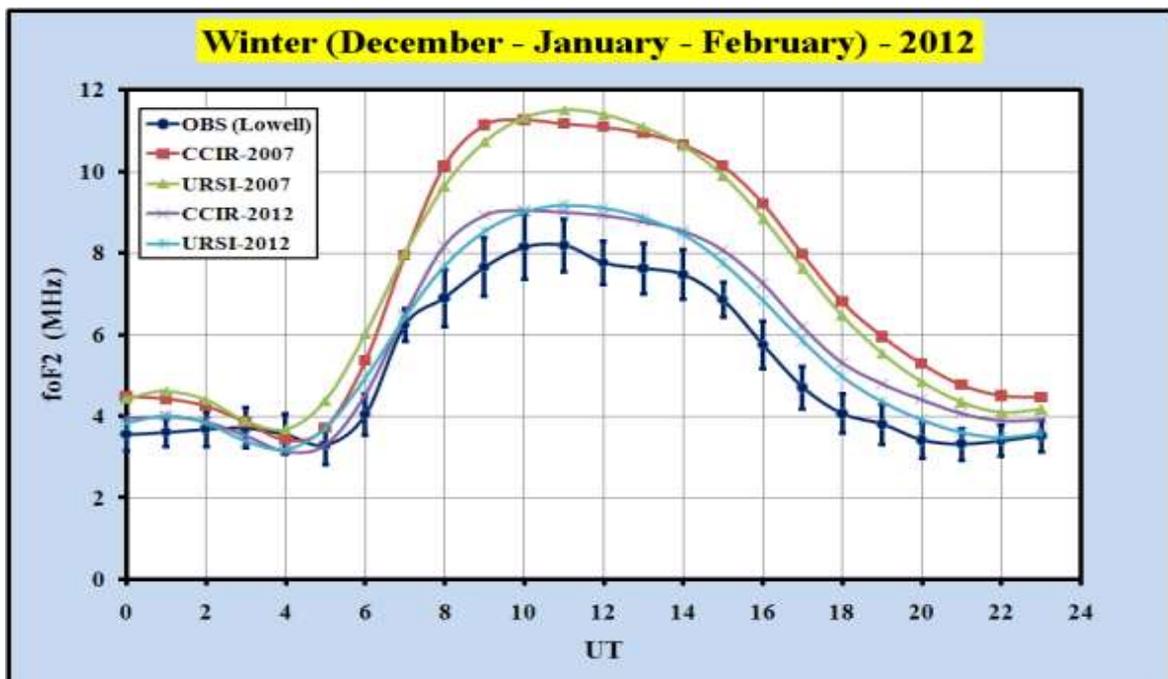


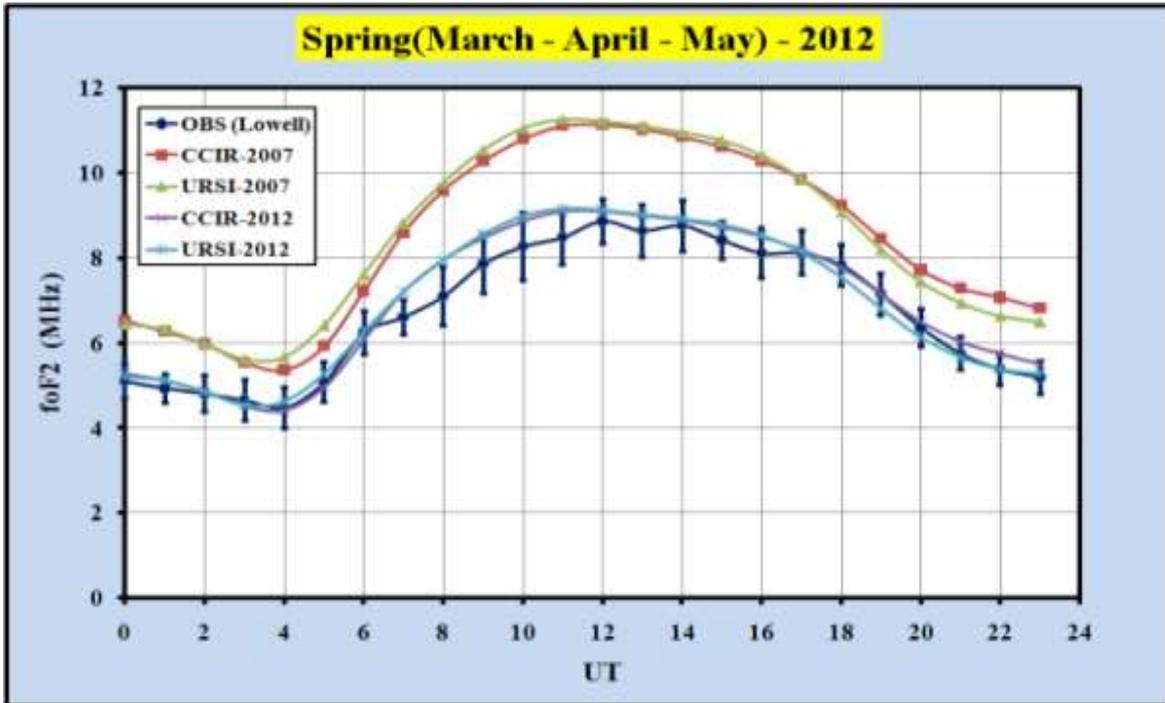
Figure (1) Sunspot Number with 12-Month Smoothed Number of Present Sunspot Number Cycle 24, Study Years are Shown in Shaded Columns.

Figure (2) shows the diurnal variations for different seasons of the observed *foF2* values from Rome station and predicted IRI-2007 and IRI-2012 (using both the CCIR and URSI Coefficients) *foF2* values.

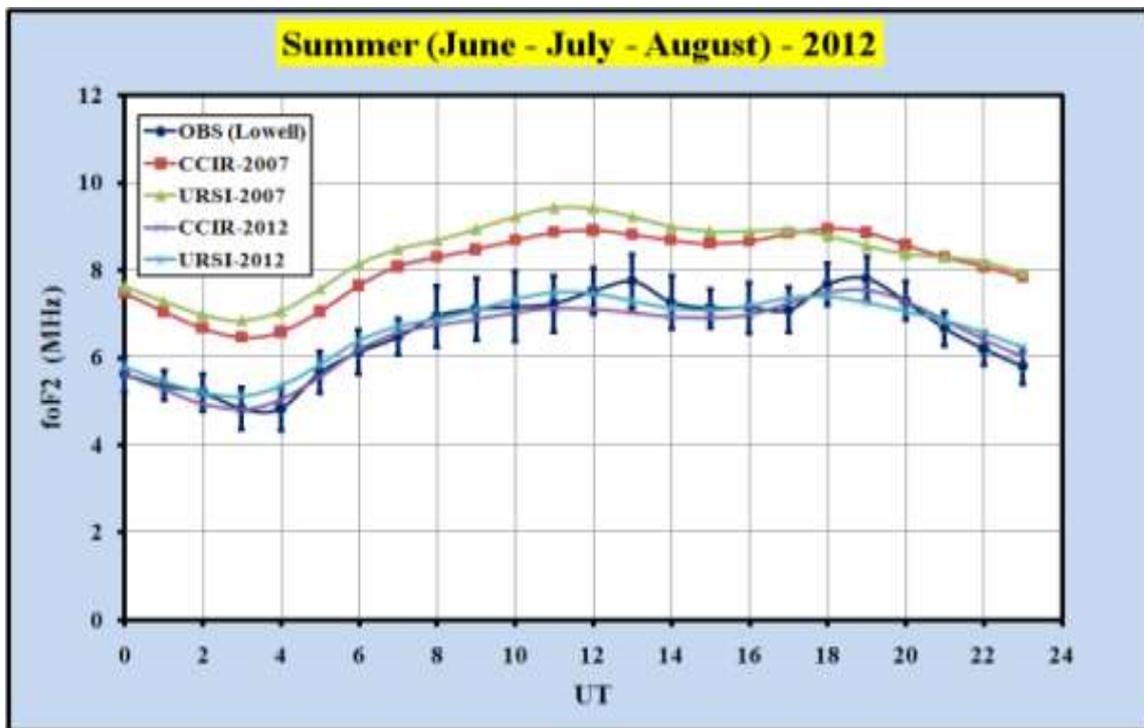
High solar Activity 2012



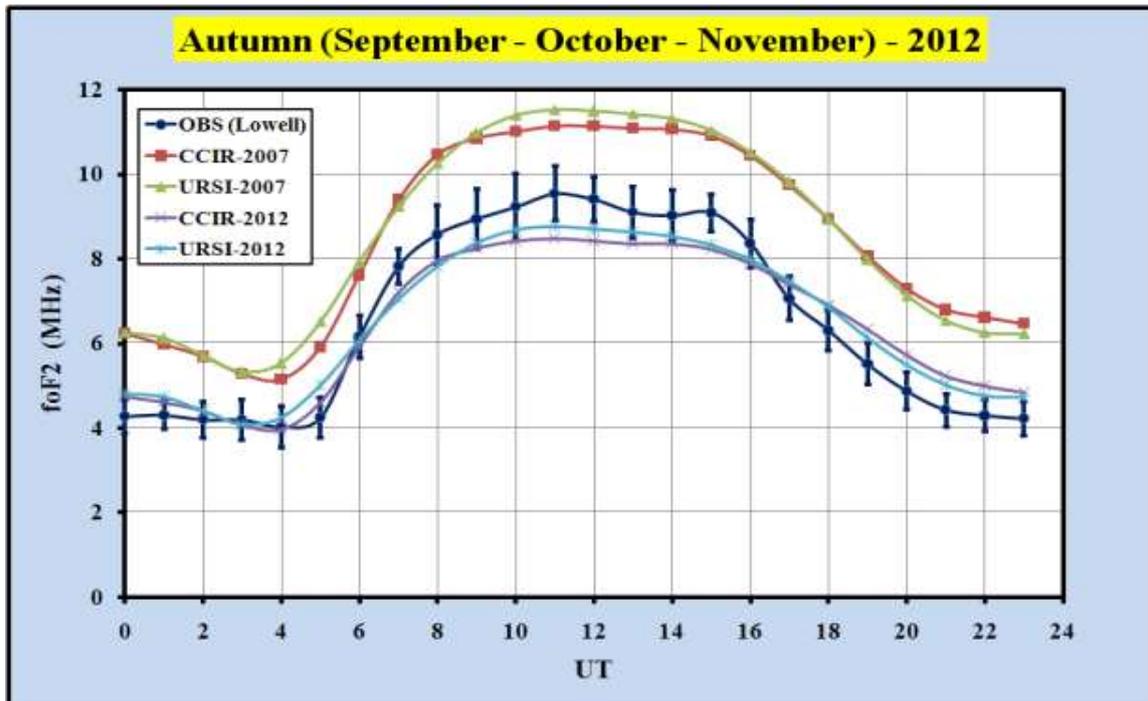
(a)



(b)



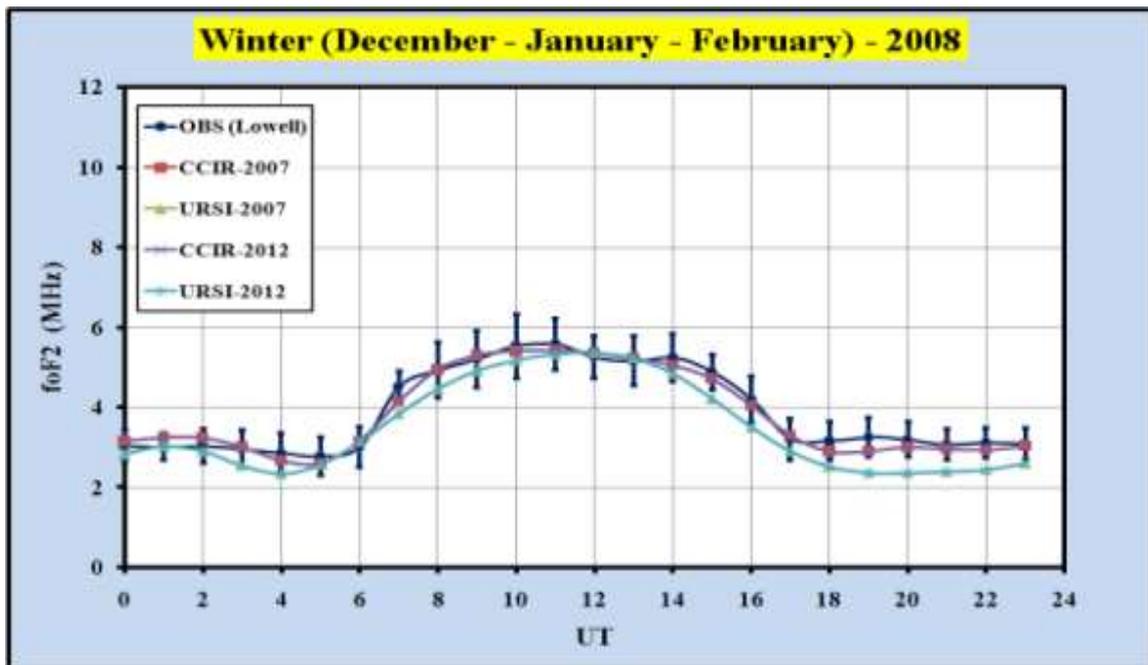
(c)



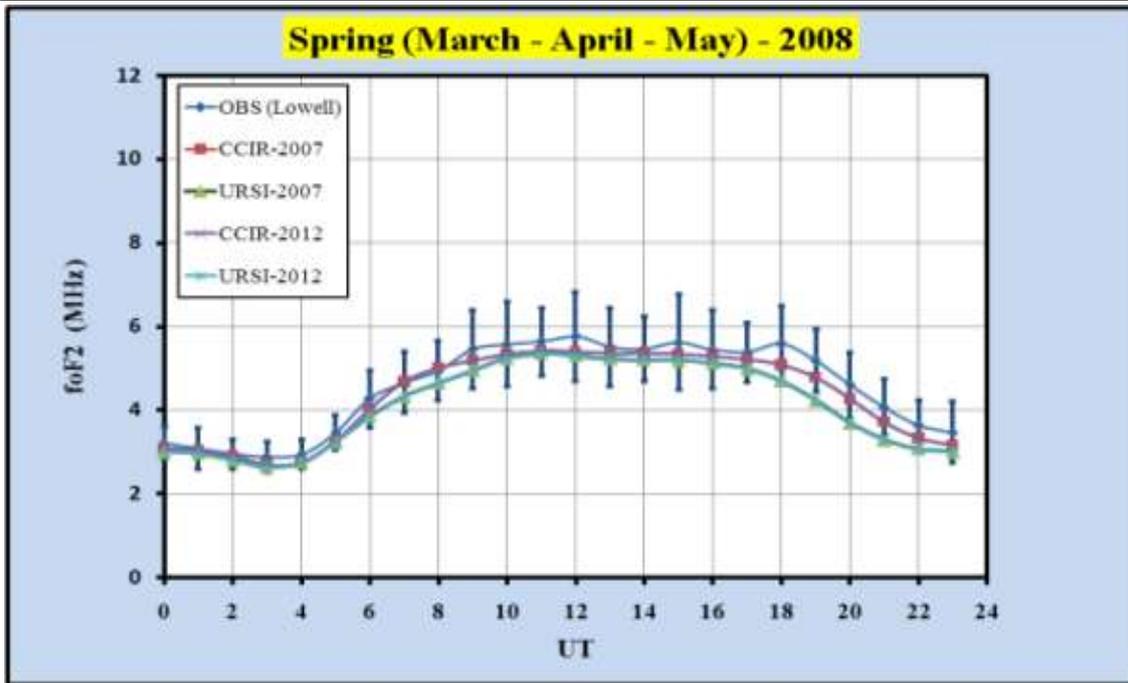
(d)

Figure (2) Plots of the Observed Diurnal $foF2$ Variations with Standard Deviations for Different Seasons (a) Winter, (b) Spring, (c) Summer, and (d) Autumn in the Year 2012 at Rome Station with IRI-2007 and IRI-2012 Model Curves, using both URSI and CCIR Coefficients.

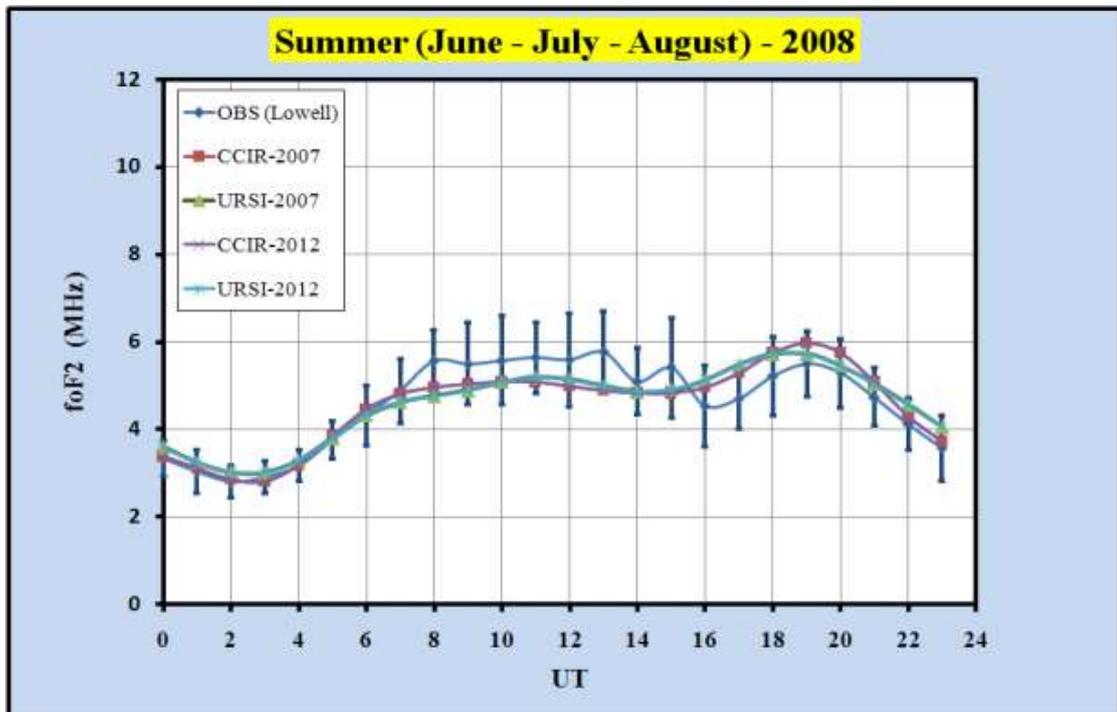
Low solar Activity 2008



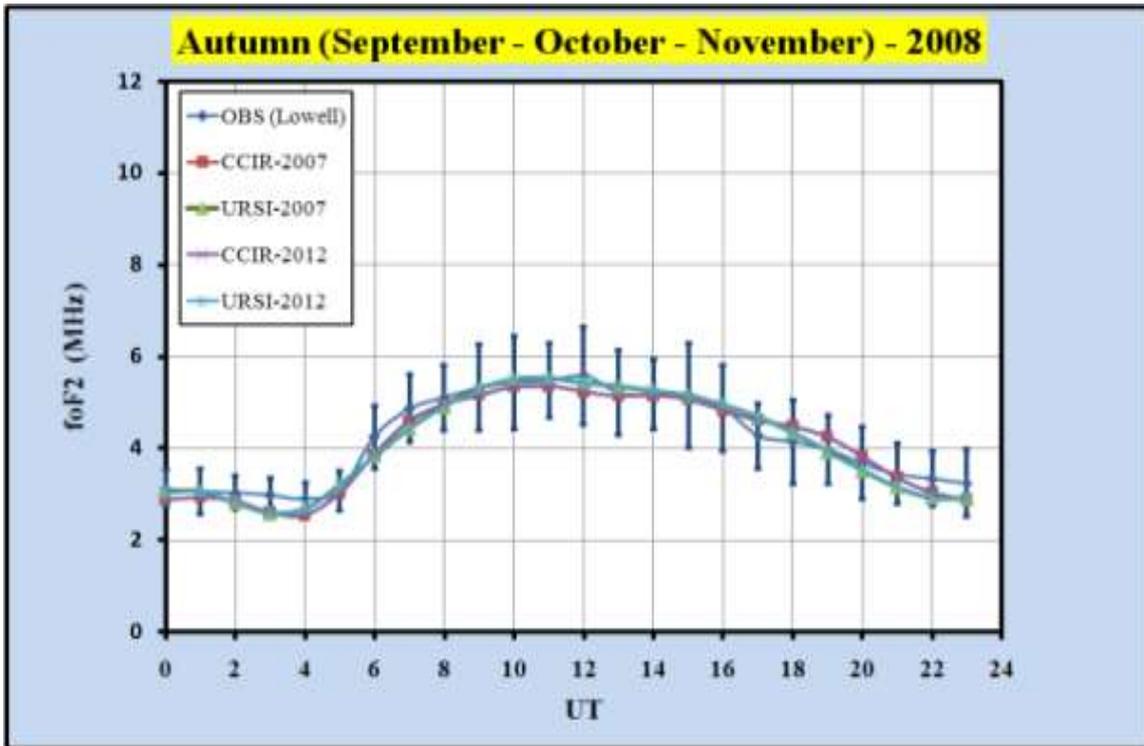
(a)



(b)



(c)



(d)

Figure (3) Plots of the Observed Diurnal $foF2$ Variations with Standard Deviations for Different Seasons (a) Winter, (b) Spring, (c) Summer, and (d) Autumn in the Year 2008 at Rome Station with IRI-2007 and IRI-2012 Model Curves, using both URSI and CCIR Coefficients.

Comparison is made for low and high solar activity years 2008 and 2012. The left four panels in figure (2) represent the diurnal average of $foF2$ with standard deviations for seasons of year 2012, while the right four panels in figure (3) for seasons of year 2008. It appears that is a good agreement between the observed $foF2$ and that given by IRI-2007 and IRI-2012 model predictions (CCIR and URSI Coefficients) for all seasons of year 2008. During Winter and Spring in 2012, observed $foF2$ values is underestimated the IRI-2007 and IRI-2012 models predictions, while observed $foF2$ values in Summer and Autumn in 2012 is underestimated the IRI-2007 model predictions and closed to IRI-2012 predictions.

Statistical analysis is applied by using relative difference $\Delta foF2\%$ between the observed $foF2$ values and that produced by IRI model (CCIR and URSI Coefficients) during low solar activity 2008 as shown in figure (4). It can be seen from figure 4(a), (b) that, $\Delta foF2\%$ between predicted values of $foF2$ from IRI-2007 and IRI-2012 using CCIR Coefficient and observed values, was high (IRI is overestimate observed $foF2$) especially at day hour (13 UT) in Summer, while URSI results in (c), (d) of figure (4) give a high $\Delta foF2\%$ at hours (4,16,17,18,19,20,21,22,23UT)in Winter season.

Figure (5) show $\Delta foF2\%$ between predicted values of $foF2$ from IRI-2007 and IRI-2012(CCIR and URSI Coefficients), and observed values during high solar activity year 2012.

Figure 5(a), (c) show that $\Delta foF2\%$ between IRI-2007 (CCIR and URSI Coefficients) and observed values, was high (IRI is overestimate observed $foF2$) at most of day hours and for all seasons, while $\Delta foF2\%$ between IRI-2012 (CCIR and URSI Coefficients) and observed values, was low (Observed $foF2$ is overestimate IRI) at

most of day hours and for all seasons, as shown in figure 5 (b), (d).

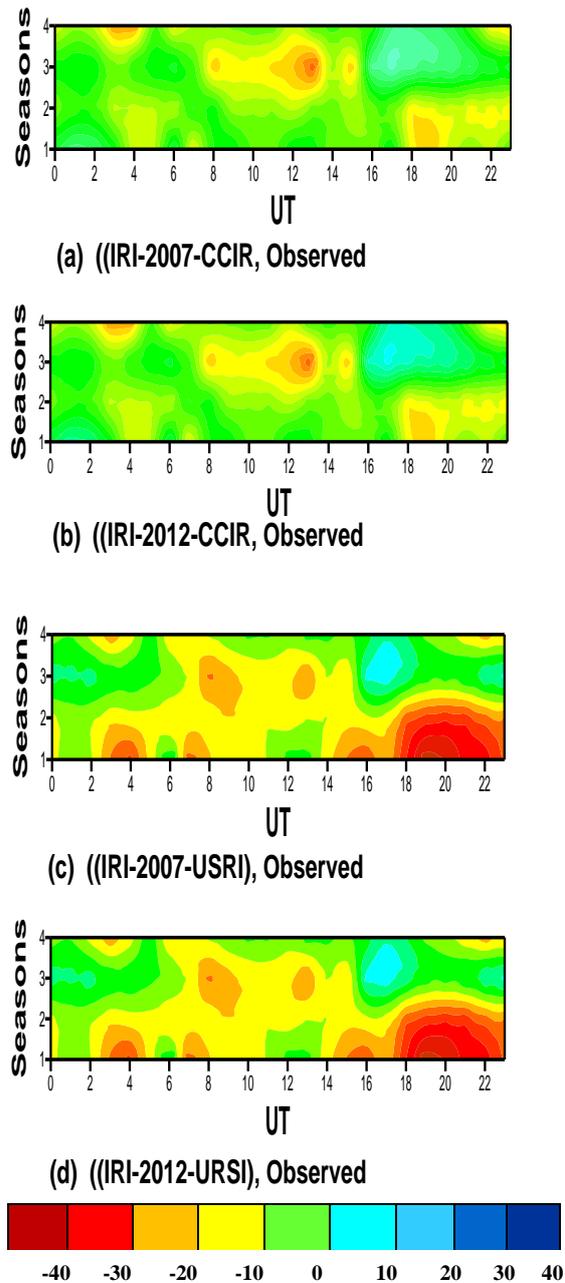


Figure (4) Contour Plots of the $\Delta foF2\%$ between (a) (IRI-2007-CCIR) and OBS, (b) (IRI-2012-CCIR) and OBS, (c) (IRI-2007-URSI) and OBS, (d) (IRI-2012-URSI) and OBS During Seasons: (1= Winter, 2= Spring, 3= Summer and 4= Autumn) of Low Solar Activity 2008.

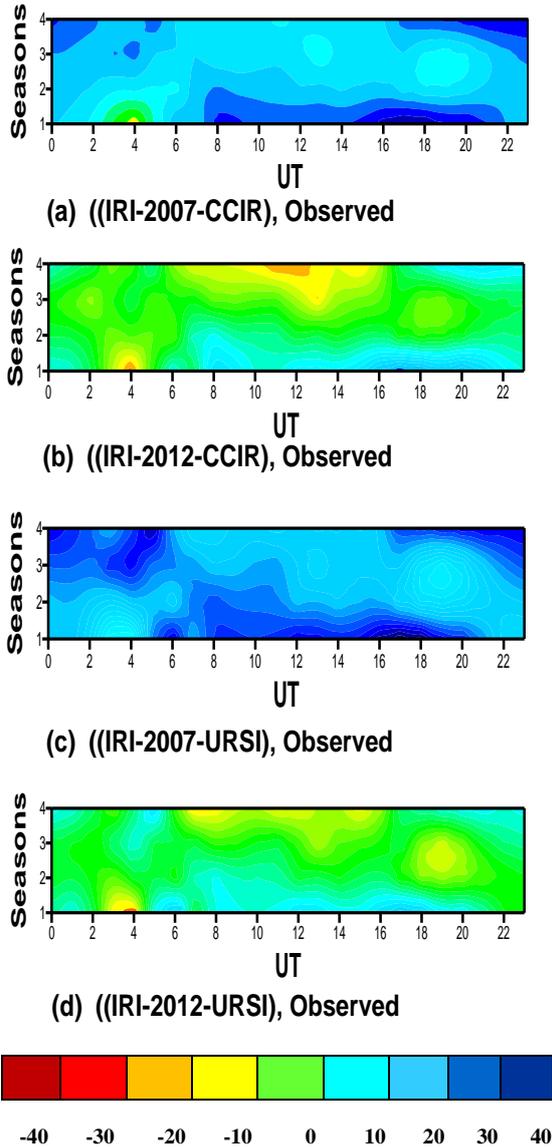


Figure (5) Contour Plots of the $\Delta foF2\%$ between (a) (IRI-2007-CCIR) and OBS, (b) (IRI-2012-CCIR) and OBS, (c) (IRI-2007-URSI) and OBS, (d) (IRI-2012-URSI) and OBS During Seasons (1=Winter, 2=Spring, 3=Summer, and 4=Autumn) of High Solar Activity 2012.

Table (1) Seasonal Day and Night Mean Relative Difference $\Delta foF2\%$ between the Predicted Values from IRI- 2007, IRI-2012 and Observed $foF2$ to the Observed Values for Rome During Low Solar Activity Year (2008).

Low Solar Activity (2008)								
Seasons	IRI-2007 CCIR		IRI-2007 URSI		IRI-2012 CCIR		IRI-2012 URSI	
	Day	Night	Day	Night	Day	Night	Day	Night
Winter	-8.9497	-2.1263	-8.9497	-18.452	-1.59	-2.113	-8.9357	-18.428
Spring	-3.9294	-6.4925	-8.1053	-12.834	-3.9156	-6.4731	-8.0901	-12.823
Summer	-4.5153	3.29728	-4.3698	5.86435	-4.5078	3.30173	-4.3547	5.87207
Autumn	-1.6692	-5.8585	-0.4855	-6.39	-1.6555	-5.8401	-0.4681	-6.3701

Table (2) Seasonal Day and Night Mean Relative Difference $\Delta foF2\%$ between the Predicted Values from IRI- 2007, IRI-2012 and Observed $foF2$ to Observed Values for Rome During High Solar Activity Year (2012).

High Solar Activity (2012)								
Seasons	IRI-2007 CCIR		IRI-2007 URSI		IRI-2012 CCIR		IRI-2012 URSI	
	Day	Night	Day	Night	Day	Night	Day	Night
Winter	31.13646	19.111	30.98354	18.92882	14.24161	8.17392	12.89147	4.354018
Spring	20.71521	19.27491	21.86163	18.64984	4.140115	2.009674	4.416146	0.213967
Summer	17.04095	21.66406	20.21919	23.3935	-2.58702	0.179643	0.283075	2.556574
Autumn	19.06135	29.71194	20.27777	30.05945	-6.37918	8.621061	-4.86969	8.87947

It can be seen from tables 1 and 2 that $\Delta foF2\%$ by using IRI-2007 and IRI- 2012 models, and observed $foF2$, in general, was low in low solar activity year 2008 and high in high solar activity year 2012. At day and night time, IRI-2012 by using both of CCIR and URSI Coefficients, $\Delta foF2\%$ was lower than the results from IRI-2007 for all seasons.

Conclusions

The results of the IRI-2007 and IRI-2012 models with the observations of critical frequencies $foF2$ conducted with the ionospheric sounder DPS-4 at Rome for low and high solar activity, have examined.

By analyzing the diurnal and seasonal averages of $foF2$ values for Rome in comparison with those predicted in the IRI-2007 and IRI-2012 models during low solar activity 2008 and high solar activity 2012, it was achieved that :

There is a very close similarity in the pattern of the daily variation of $foF2$ values for all seasons and for different solar activity.

In low solar activity 2008, both the CCIR and URSI Coefficients of the IRI-2007 and IRI-2012 models give $foF2$ values close to the ones measured.

In high solar activity 2012, the results of the IRI-2007 (CCIR and URSI Coefficients) are overestimated the measured values of $foF2$ for all seasons, but IRI-2012 model gives $foF2$ values close to the ones measured.

The CCIR results give more accurate predictions than the URSI results; because CCIR model is recommended over the continents (where Rome station location is over the continents and not over the ocean, so that the prediction results are more accurate by CCIR), while the URSI model is over the oceans.

Using a lot of years to make the results of seasonal mean relative difference $\Delta foF2$ % by using IRI-2007 model(CCIR Coefficient) are very close to its results by using IRI-2012 model(CCIR Coefficient) and the same with respect to (URSI Coefficient) for both day and night.

Acknowledgments

We would like to thank D. Bilitza at NASA/GSFC, Heliospheric Physics Lab. for his cooperation by giving the web site of the IRI-2012

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